PRINCETON
APPLIED
RESEARCH

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PRINCETON APPLIED RESEARCH CORPORATION

PRINCETON, NEW JERSEY

INSTRUCTION MANUAL

LOCK-IN AMPLIFIERS
MODELS JB-4 AND JB-5

THIS MANUAL APPLIES SPECIFICALLY TO MODEL JB-5 SERIAL NO. 1150

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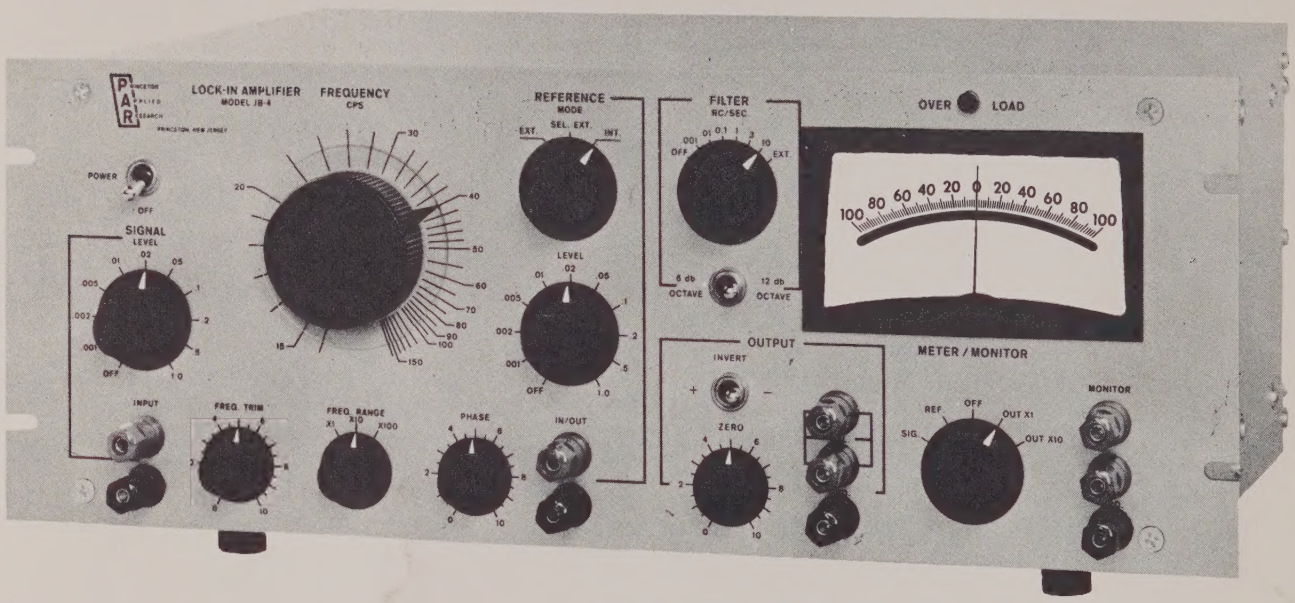
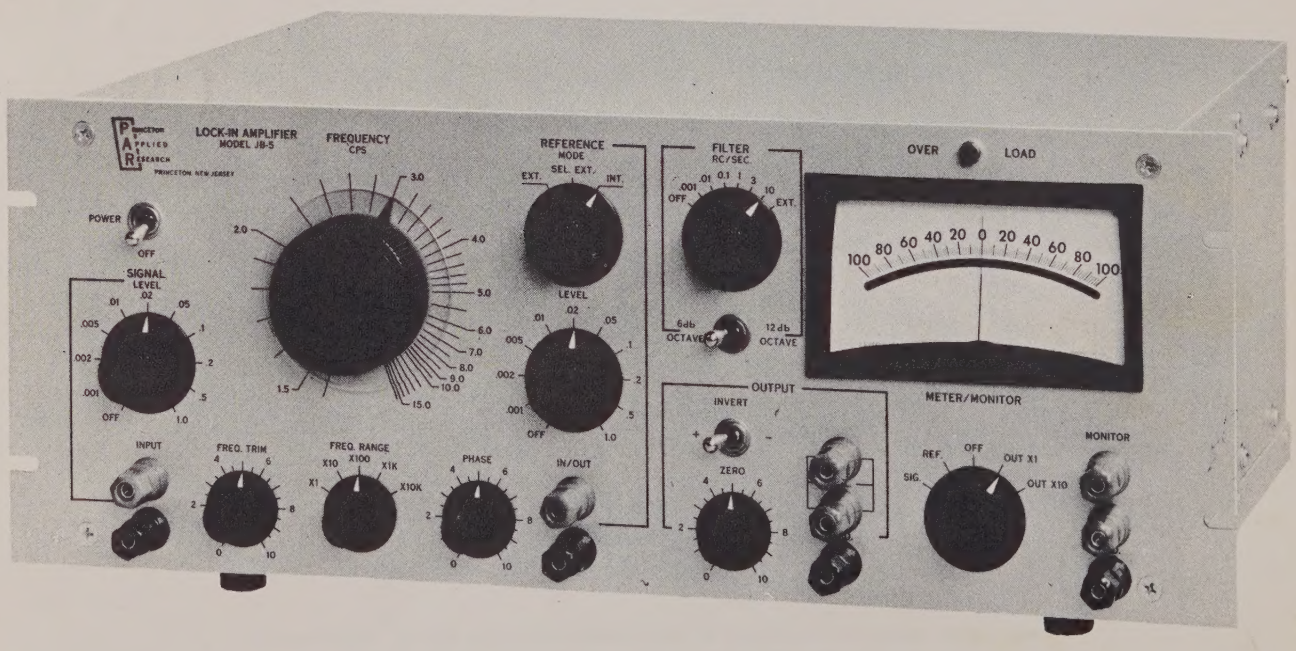


MODEL JB-4



MODEL JB-5

SECTION I.

SPECIFICATIONS

GAIN: (rms AC in to push-pull DC out) Greater than 9,000. One-half millivolt rms input signal coherent with reference signal will drive output meter to full scale.

NOISE REJECTION: A signal 46 db below ambient white noise in a 1 KC bandwidth centered about signal frequency may be recovered with a signal-to-noise ratio of 1.

EQUIVALENT INPUT NOISE*: Equivalent input noise for a typical production unit measured with the input terminals shorted in a 1 cps bandwidth at 1KC is approximately 150 nanovolts rms.

EQUIVALENT NOISE BANDWIDTH: 0.024 cps minimum (10 seconds maximum internal RC integrating time). 6 or 12 db per octave roll-off selectable by front panel switch.

TIME CONSTANTS: 0, 0.001, 0.01, 0.1, 1, 3, 10 secs; and EXT. Single or double section RC filtering. In the EXT. position appropriate points internal to the instrument are brought out to a rear connector where capacitance may be added to obtain any desired electronic integrating time constant.

HARMONIC REJECTION: Second harmonic down by a factor of 1000 or 60 db. Third harmonic down by a factor of 200 or 46 db.

OVERLOAD INDICATOR: Light indicates overload condition at critical circuit points.

LINEARITY: Better than ±1% of full scale.

ZERO DRIFT: ±½% of full scale per hour maximum.

POWER REQUIREMENTS: 105-125 volts or 210-250 volts; 50-60 cps; 10 watts.

SIGNAL CHANNEL CHARACTERISTICS:

INPUT IMPEDANCE: Approximately 50 K.

INPUT LEVEL CONTROL: Input signal may be attenuated up to a factor of 1000 in steps of 1.0, .5, .2, .1, .05, .02, .01, .005, .002, .001; accuracy ±5%.

FREQUENCY SELECTIVE AMPLIFIER: Selectivity characteristic of tuned amplifier in signal channel is that of parallel resonant circuit with a Q of approximately 25. (Not twin-T type)

*See additional information on Page 4

REFERENCE CHANNEL CHARACTERISTICS: The reference signal, by which the signal to be measured is demodulated, is obtained by three modes of operation; INTERNAL, EXTERNAL and SELECTIVE EXTERNAL.

SELECTIVE EXTERNAL MODE: Externally generated reference signal filtered by tuned amplifier having characteristics of parallel resonant circuit with a Q of approximately 25, phase shifted and applied directly to demodulator. Minimum of 100 millivolts peak-to-peak reference signal required.

EXTERNAL MODE: Externally generated reference signal phase shifted and applied directly to demodulator. 5 volts peak-to-peak reference signal required

INTERNAL MODE: Self-contained oscillator drives demodulator (through phase shifter) directly. Output frequency appears as sine wave at "REFERENCE IN/OUT" terminals. Maximum output approximately 5 volts peak-to-peak at 3 ma maximum.

PHASE ADJUSTMENT: Provides minimum of 180° of continuous phase change at any frequency. Also 180° INVERT switch.

OUTPUT: Will drive most galvanometric or servo recorders. Also direct reading panel meter.

LEVEL: Maximum DC output

a) into high impedance load ±5 volts.
b) into pen recorder of less than 2 K resistance ±1 milliamp or ±½ milliamp (switch selectable)

COMMON MODE QUIESCENT VALUE: —6 volts DC

MONITOR: A five position switch allows the panel meter and monitor output terminals to be switched to SIGNAL, REFERENCE, OFF and two output points in the instrument, OUT XI and OUT X10 for level monitoring, setting-up, zeroing, etc. The meter indicates the peak-to-peak AC voltage when it is switched to REFERENCE and SIGNAL positions.

WEIGHT: Approximately 15 lbs.

SIZE: 19" W x 7" H x 11" D.

FINISH: Iridited aluminum case, light grey front panel.

ACCESSORIES: PAR Model CR-4 Preamplifier. PAR Model BZ-1 Mechanical Light Chopper.

WARRANTY: 1 year.
Specifications subject to change without notice.

NOTES

***LOW-NOISE SIGNAL CHANNEL AMPLIFIER (LIA-1066):** When the desired input signal is equal to the internal noise of the Lock-In Amplifier, the output signal-to-noise ratio will be unity. This condition may be improved upon by 1) increasing the level of the input signal by means of a preamplifier such as the PAR Model CR-4, or 2) reducing the internal noise of the Lock-In Amplifier. The internal noise of the Lock-In Amplifier may be reduced by interchanging the standard SIGNAL CHANNEL TUNED AMPLIFIER BOARD No. TA0209A with LOW-NOISE SIGNAL AMPLIFIER BOARD No. LIA-1066. Specifications which differ from those presented on page 3 when the LIA-1066 AMPLIFIER is used are as follows:

GAIN: Increases over-all gain by a factor of 10.

SIGNAL CHANNEL SELECTIVITY: Untuned, wideband amplifier with a Q of approximately 1/3.

EQUIVALENT INPUT NOISE: Equivalent input noise for a typical production unit measured with the input terminals shorted in a 1 cps bandwidth at 1KC is approximately 5 nanovolts rms.

FREQUENCY DEPENDENCE OF OPERATING PARAMETERS:

TUNED AMPLIFIER Q: The effective Q of both the signal and reference channel tuned amplifiers varies somewhat with frequency. It is normally adjusted to a value of 25 at 400 cps. and will be found to vary somewhat above and below this value as the instrument is tuned through its frequency range. If, at a specific frequency, a Q value is desired (for either signal or reference channel) other than that obtained with the instrument as factory adjusted, it may be obtained by making use of the internal Q adjustment (see "ALIGNMENT INSTRUCTIONS"). This adjustment allows the Q to be set to 25 at any frequency within the range of the instrument.

In some applications it will be desirable to operate with Q values less than 25. The Q adjustment may be used to implement such operations. Operation with Q values higher than 25 is **not** recommended.

OPERATION ON X1 FREQUENCY RANGE: (FOR MODEL JB-5 ONLY) Those who are forced to operate at frequencies in this range should be aware of the behavior of tuned amplifiers at these frequencies. Their behavior is similar to that of a parallel RLC tuned circuit with a Q of 25. The rise time (0 to 63%) of such a tuned circuit, whose resonant frequency is f_o is given by:

$$t_r = \frac{Q}{\pi f_o}$$

For a frequency of 1.5 cps this gives a rise time of the order of 5 seconds. This sets the time lag between any change made in the input level to, or the center frequency of the tuned amplifier and the resulting response. Furthermore any transient which affects the tuned amplifier will set up a ringing response which will take a time of this order to decay. As a result, tuning and level setting at very low frequencies often becomes a test of patience. If at all possible, at such frequencies it would be desirable to reduce the Q of the tuned amplifier, and to make up the lost gain by means of a low-pass preamplifier.

It will also be noted that the internal noise in the JB-5 increases noticably at the low end of its frequency range. This is due to the well known 1/f component in the noise generated by transistors (and tubes for that matter). In general the noise figure of a transistor amplifier begins to deteriorate below about 100 cps. The internal noise level of the JB-5 at the extreme low end of its range is somewhat higher than at say 400 cps. However, it will be observed that with a long filter time constant (e.g. 10 seconds) in use the output noise is at an acceptable level. Since lock-in operation at these low frequencies always entails the use of time constants of this order, it is only noise output under such conditions that is meaningful. A careful check of the "AC BALANCE ADJUSTMENT" should be performed to make certain that mixer unbalance is not contributing to output fluctuations seen at low frequencies without filtering. If sufficient gain is provided ahead of the JB-5 it will be possible to swamp its internal noise with noise accompanying the signal at any frequency. The user should carefully examine his input signal level to determine his requirements for preamplification at any operating frequency.

SECTION II.

PRELIMINARY INSTRUCTIONS

COOLING:

Because of the low total power consumption of the instrument its case is unventilated. At installation the only precaution to be observed is to insure that the ambient temperature in which it is operated will not exceed 45°C (113°F). This will insure trouble-free continuous operation.

POWER REQUIREMENTS:

The instrument requires approximately 10 watts at either 105 to 125 V. AC or 210 to 250 V. AC; 50 to 60 cycles. It is normally shipped wired for 105 to 125 V. operation. If it is shipped wired for 210 to 250 V. operation, the line cord will bear a tag at the plug end so marked. Transformer primary connections for changing from 117 V. AC to 234 V.AC or vice versa are illustrated in Figure 1 and the procedure for making this change is outlined below.

1. Remove the top, bottom and back sheet metal covers. (Each of these is held by 6 screws.)
2. Remove the right (viewed from the front) side panel by removing the 4 screws securing it to the printed circuit board assembly, and the 2 screws securing it to the front panel. Easy access to the power transformer may now be had from the right side of the instrument.
3. The transformer primary connections for 117 V. AC operation are shown in Figure 1A.
4. The transformer primary connections for 234 V. AC operation are shown in Figure 1B. The case is reassembled by reversing the above procedure.

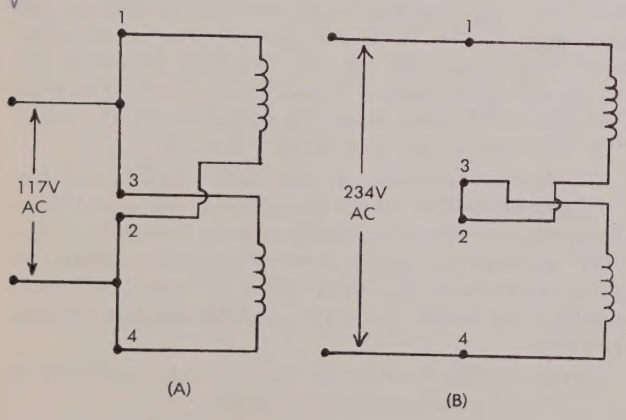


FIGURE 1

TRANSFORMER PRIMARY CONNECTIONS FOR OPERATION FROM EITHER 117 V. AC OR 234 V. AC

FUSING:

A ¼ A. slo-blo 3AG 250 V. fuse is supplied, and gives adequate protection to the instrument in either 105 to 125 V. operation or in 210 to 250 V. operation at 50 to 60 cps.

FRONT PANEL CONTROLS AND CONNECTIONS

POWER:

In the "OFF" position this switch completely disconnects the power line from the instrument.

SIGNAL LEVEL:

This control sets the fraction of the voltage applied to the "SIGNAL INPUT" terminals which reaches the input of the signal channel tuned amplifier.

SIGNAL INPUT:

These terminals are connected to the input of the signal channel tuned amplifier via the "SIGNAL LEVEL" control. This input is single-ended. The red binding post is the "high" side; the black binding post is connected to chassis ground. A resistance of 54 K ± 5% (the resistance of the "SIGNAL LEVEL" control) is internally connected directly across these terminals.

CAUTION: THE VOLTAGE (DC + PEAK AC) APPLIED BETWEEN THESE TERMINALS SHOULD NEVER EXCEED ±25 V.

FREQUENCY:

This dial simultaneously tunes the reference and signal channel tuned amplifiers. The **reference frequency** in cps is the reading on the dial times the reading on the "FREQ. RANGE" switch. The accuracy of this frequency setting is ±5%.

FREQUENCY RANGE:

This switch selects the range which can be continuously tuned by the "FREQUENCY" dial. This setting applies to both the signal and reference channels.

FREQUENCY TRIM:

This control varies the frequency of the signal channel tuned amplifier only. Total variation is approximately ±5%. It is used to peak the signal channel at any given frequency setting, thus compensating for possible errors in tracking between the signal and reference tuned amplifiers.

PHASE:

This control varies the phase of the reference relative to the signal. It provides a continuously variable shift of at least 180° at any frequency within the range of the instrument.

REFERENCE MODE:

This switch is used to select one of the three modes of reference operation. (See "OPERATING INSTRUCTIONS" for a detailed description of the three possible modes of operation).

REFERENCE LEVEL:

In the ("EXT." / "SEL EXT.") mode, this control sets the fraction of the voltage applied to the "REFERENCE IN/OUT" terminals which reaches the input of the (phase shifter / reference channel tuned amplifier). In the "INT." mode it controls the level of the sinusoidal output voltage appearing at the "REFERENCE IN/OUT" terminals.

REFERENCE IN/OUT:

In the "EXT." reference mode these terminals connect to the input of the phase shifter via the "REFERENCE LEVEL" control. In the "SEL. EXT." mode these terminals connect to the input of the reference channel tuned amplifier via the "REFERENCE LEVEL" control. In either case the red binding post is the "high" side of the single-ended input, the black binding post being connected to chassis ground. In either mode a resistance of 54 K ±5% (the resistance of the "REFERENCE LEVEL" control) is connected directly across these terminals.

In the "INT." reference mode a sine wave signal at the reference frequency appears at these terminals. Its amplitude is set by the "REFERENCE LEVEL" switch. With this switch in the "1" position the sine wave output is approximately 5 V. peak-to-peak. In any other position the output is the fraction of this value indicated by the "REFERENCE LEVEL" control. The output from these terminals is single-ended, the red binding post being the "high" side and the black binding post being chassis ground. The impedance seen looking into these terminals varies with the "REFERENCE LEVEL" setting. It has a maximum value of approximately 1.4 K when this switch is in the "0.5" position.

FILTER:

This switch determines the time constant of the RC low-pass filter at the output of the mixer. The number at each switch position gives this time constant in seconds. In the "OFF" position there is no internal low-pass filtering at all. In the "EXT." position the filtering time constant is determined by external capacitors.

6 DB – 12 DB PER OCTAVE SWITCH:

This switch sets the roll-off of the RC low-pass filter at the mixer output to either "6 DB/OCTAVE" (single RC filtering) or "12 DB/OCTAVE" (double RC filtering). In either case the time constant of the filtering is as set on the "FILTER" switch. This switch is also operative when external capacitors are used.

OUTPUT:

This group of 3 terminals is provided to drive a galvanometric recorder having a 0-1 ma movement and an internal resistance of less than 2K. When the panel meter (with the "METER/MONITOR" switch in "OUT X1" or "OUT X10" position) reads zero, the two red binding posts are at the same voltage and are both at approximately –6V relative to chassis ground. The impedance seen looking into these two terminals is approximately (5K / 10K) when the recorder switch on the rear panel is in (1ma / ½ma) position. The black binding post is chassis ground.

INVERT:

This switch inverts the phase (i.e. produces a 180° phase change) of the reference. It has the effect of inverting the sense of the mixer output voltage.

ZERO:

This control sets the quiescent DC level of the output. It may be used to set the quiescent reading of the panel meter and to set the pen recorder (if used) to zero with no signal input.

METER/MONITOR SWITCH:

This switch performs two functions. It determines the internal point in the instrument monitored by the panel meter and simultaneously connects the same point to the "MONITOR" terminals for oscilloscope monitoring.

1. Panel meter: In the "SIG." position of the "METER/MONITOR" switch the meter indicates the output level of the signal channel tuned amplifier. In the "REF." position it indicates the output level of the phase-shifter. In the "OFF" position the panel meter is completely disconnected. In the "OUT X1" position the panel meter reads the output of the DC amplifier following the mixer, full scale being 5 V. DC. In the "OUT X10" position the panel meter reads the output of the DC amplifier, full scale in this case being 0.5 V. DC.

2. Monitor terminals. In the "SIG." position of the "METER/MONITOR" switch the output of the signal channel tuned amplifier is available at these terminals. In the "REF" position the output of the phase-shifter appears at these terminals. In the "OFF," "OUT X1" and "OUT X10" positions the output of the DC amplifier appears at these terminals.

Notes: 1) The function of the "OUTPUT" terminals is unaffected by this switch.

2) It is undesirable to operate the instrument with the "METER/MONITOR" switch in the "SIG." or "REF." positions as the loading due to the meter circuit produces unbalances in the amplifiers being monitored.

MONITOR TERMINALS:

This group of 3 terminals provides for oscilloscope monitoring of all important internal waveforms and also provides a low-impedance voltage output from the instrument in cases where such is desired. The waveform appearing at these terminals depends on the setting of the "METER/MONITOR" switch.

1. "SIG." position: In this case the two red binding posts are connected to the two outputs (push-pull) of the signal channel tuned amplifier. The upper one is at a DC level of approximately −5V. and the lower at approximately −15V., relative to chassis ground.

2. "REF." position: In this position the upper red binding post is connected to the output (single-ended) of the phase-shifter. The lower one is connected to chassis ground.

3. In the "OFF," "OUT X1" and "OUT X10" positions of the "METER/MONITOR" switch the two red binding posts are connected to opposite ends of the output (push-pull) of the DC amplifier following the mixer. When the panel meter reads zero (in "OUT X1" or "OUT X10" positions) the voltage between these binding posts is zero. In this case both binding posts are at approximately −6V. relative to chassis ground. When the DC amplifier is delivering maximum output the DC voltage appearing between these terminals is ±5 V (corresponds to ± full scale reading on the panel meter with "METER/MONITOR" switch in "OUT X1" position). The voltage appearing between these terminals is the same in any of the last three ("OFF," "OUT X1" or "OUT X10") positions of the "METER/MONITOR" switch.

The black binding post is connected to chassis ground in any position of the "METER/MONITOR" switch.

OPERATING INSTRUCTIONS

GENERAL:

PAR Lock-In Amplifiers are essentially detection systems capable of operating with an extremely narrow equivalent noise bandwidth. Their function is to select a band of frequencies from a signal spectrum applied to their input and to convert the information therein to an equivalent bandwidth at DC. The center frequency of the band so selected is equal to the reference frequency being used.

Figure 2 is a block diagram of the instrument. The signal containing the information to be detected is applied to the "SIGNAL INPUT" terminals. An appropriate fraction of this signal is picked off by the "SIGNAL LEVEL" control and applied to the input of the signal channel tuned amplifier. The role of this tuned amplifier is twofold:

1. By limiting the bandwidth at the detector input it increases the percentage of the peak input voltage to the detector which is due to the desired signal.

2. It attenuates components in the signal spectrum at the odd harmonics of the reference frequency to which the phase-sensitive detector is sensitive. (This sensitivity to odd harmonics of the reference frequency is due to the use of a switching type phase-sensitive detector).

The output of the signal channel tuned amplifier is applied to the input of the phase-sensitive detector. This is essentially a device which mixes the signal and reference frequencies so as to produce corresponding sum and difference frequencies at its output. A low-pass filter at the output of the phase detector rejects the high frequency components corresponding to sum frequencies, and passes those of the difference frequencies that lie within its pass-band. In particular, the difference frequency due to components of the signal at the reference frequency is DC. Components of the signal spectrum at frequencies differing from the reference frequency by more than the cut-off frequency of the low-pass filter will produce difference frequencies which will be attenuated by it. Consequently the output from the low-pass filter will be due to that portion of the signal spectrum which lies within a band of frequencies about the reference frequency determined by the pass-band of the filter.

The reason a mixer of this type is called a phase-sensitive detector is that the DC output produced by it due to a signal at the reference frequency is proportional to the cosine of the relative phase of the signal and reference. This property is made explicit use of in some lock-in amplifier applications.

The reference frequency for this instrument may be generated internally or obtained from an external source. In either case a variable phase-shifter is available in order to allow the relative phase of the signal and reference to be adjusted as desired.

A detailed description of the operation of the instrument follows:

REFERENCE CHANNEL:

The operation of the reference channel depends on the mode being used. Consequently, the three available modes are treated separately.

EXTERNAL:

This mode is used when a sine wave of at least 5V peak-to-peak is available for reference (at this level the mixer is insensitive to small changes in reference amplitude). If a reference waveform meeting these requirements is available it can be coupled into the instrument via the "REFERENCE IN/OUT" terminals located directly below the "REFERENCE LEVEL" control on the front panel. This input is single-ended, the red binding post being the "high" side and the black one being chassis ground. A resistance of 54K ±5% (the "REFERENCE LEVEL" control) is internally connected directly across these terminals (see FIG. 2). In this mode of operation the only adjustment required is to set the reference amplitude at the proper value. With the instrument power

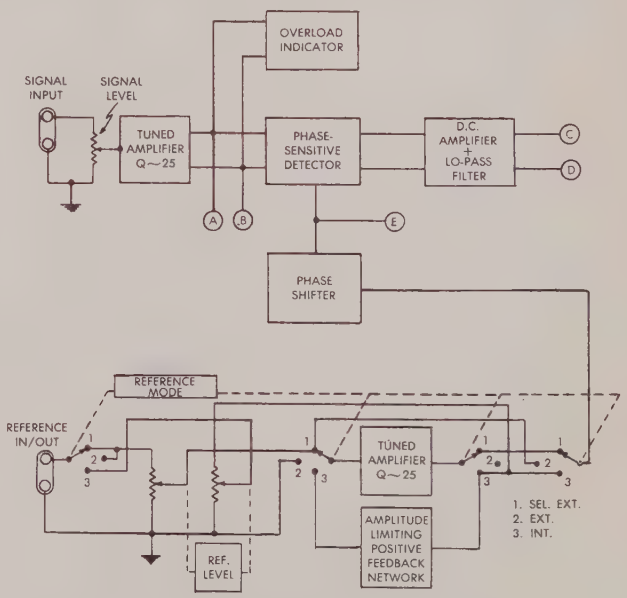


FIGURE 2

BLOCK DIAGRAM PAR LOCK-IN AMPLIFIERS
MODELS JB-4 AND JB-5

on and the reference source output connected to the "REFERENCE IN/OUT" terminals, set the "REFERENCE LEVEL" control at "OFF," the "REFERENCE MODE" switch to "EXT." and the "METER/MONITOR" switch to "REF." Connect the input of an oscilloscope to the upper of the two red "MONITOR" terminals and the ground on the

oscilloscope to the black terminal. Rotate the "REFERENCE LEVEL" control until the amplitude of the sine wave seen on the oscilloscope is between 4 and 6 volts peak-to-peak. Note the reading on the panel meter. This reading corresponds to a proper reference level for your instrument and may be used for checking and resetting. (NOTE: A slight flattening of the positive peak of the sine wave may be observed. This is in no way harmful to the operation of the instrument).

The instrument is now set up for operation in the "EXT." reference mode.

SELECTIVE EXTERNAL MODE:

In any reference mode the reference signal is passed through the phase-shift network before being applied to the detector. The detector is essentially a double-pole double-throw switch which is driven at the reference frequency. A square wave is required to drive the switch. This square wave is obtained by feeding the output of the phase shifter into a Schmitt trigger circuit. Certain non-sinusoidal waveforms applied to the input of the phase shifter will produce output waveforms which will result in improper triggering of the Schmitt and consequent improper operation of the detector. For this reason if the reference waveform is not sinusoidal it should be passed through the reference channel tuned amplifier in order to make it more nearly sinusoidal by reducing its harmonic content before applying it to the phase shifter. In general, this mode of operation allows a particular frequency component to be selected out of a complex waveform and used as the reference frequency.

With the instrument power on, connect the output of the reference source to the "REFERENCE IN/OUT" terminals. This input is single-ended, the red binding post being the "high" side and the black one being chassis ground. A resistance of 54 K (±5%) is internally connected directly across these terminals (the "REFERENCE LEVEL" control. See FIG. 2). Set the "REFERENCE MODE" switch to "SEL. EXT.," the "REFERENCE LEVEL" control to "OFF," and the "METER/MONITOR" switch to "REF." Set the "FREQ. RANGE" switch and "FREQUENCY" dial to the desired reference frequency. Connect the upper red "MONITOR" terminal to the input of an oscilloscope, and the oscilloscope ground to the black terminal.

Turn the "REFERENCE LEVEL" control clockwise until a sine wave appears on the scope. Adjust the "FREQUENCY" control so as to maximize the amplitude of this sine wave. Adjust the "REFERENCE LEVEL" control so that the amplitude of the maximum response so obtained is 4 to 6 V. peak-to-peak as measured by the scope. (A slight flattening of the positive peaks of the sine wave may be observed; this in no way affects proper operation of the instrument).

If the desired frequency component of the reference waveform contributes only a small percentage of its amplitude, it may not be possible to obtain a sine wave of the amplitude specified above due to the peak level of the reference waveform exceeding the limits of the tuned amplifier. If this is the case the only solution is, by means of external filtering, to reduce the amplitude of the undesired frequencies in the reference waveform before applying it to the input of the tuned amplifier.

Once a sinusoidal waveform within the above amplitude limits has been obtained at the "MONITOR" terminals, note the reading of the panel meter. This reading corresponds to a proper reference level for your instrument and can be used for re-setting and checking.

The above adjustments having been carried out, the instrument is ready for operation in the "SEL. EXT." reference mode.

INTERNAL MODE:

In general, operation in this mode requires no adjustments. However, in the case of a new instrument, operation in this mode should be checked to make sure it is proper before the instrument is used. To do this, turn the instrument power on, set the "REFERENCE MODE" switch to "INT." and the "METER/MONITOR" switch to "REF." A substantial reading should be observed on the panel meter. Connect the upper red "MONITOR" terminal to the input of an oscilloscope; connect the scope ground to the black terminal. With the "FREQUENCY" and "FREQ. RANGE" controls set to produce a 400 cps reference frequency, the amplitude of the sine wave appearing on the scope should be between 4 and 6 V. peak-to-peak (5 V. nominal). If this is not the case, refer to the "INTERNAL OSCILLATOR ADJUSTMENT" section in "ALIGNMENT PROCEDURE" and follow the alignment instructions therein.

If the level observed on the scope is within the limits specified above, the instrument is ready for use in the "INT." reference mode. Note the reading on the panel meter; this reading represents a proper reference level for your instrument. The level indicated by the meter will vary somewhat with frequency due to variation in the Q of the reference channel tuned amplifier with frequency. However, if adjusted as recommended at 400 cps this level will remain within acceptable limits over the entire frequency range of the instrument.

In this mode of operation a sinusoidal output is available at the "REFERENCE IN/OUT" terminals. This voltage has a maximum amplitude of from 4 to 6 V. peak-to-peak and is controlled by the "REFERENCE LEVEL" control (this control does **not** affect the meter reading in the "REF." position, or the amplitude seen on the scope). The impedance seen looking into the terminals under these conditions varies with the "REFERENCE LEVEL" setting, being a maximum of 1.4 K in the "0.5" position. This output is single-ended, the red binding post being the "high" side and the black one being chassis ground.

SIGNAL CHANNEL:

The "SIGNAL INPUT" binding posts are located directly below the "SIGNAL LEVEL" control on the left side of the panel. This input is single-ended, the red binding post being the "high" side and the black binding post being at chassis ground (see note).

NOTE:

When dealing with low-level signals it is important to avoid injecting spurious voltages into the "SIGNAL INPUT" due to ground currents. In general, the best arrangement is to have only one ground connection between the signal source and the Lock-In Amplifier and to make this connection to the black "SIGNAL INPUT" binding post. In cases where large ground currents flow between the Lock-In Amplifier chassis and the signal source, other arrangements may be better; the best one in a given situation can only be determined by trial and error.

A 54 K (±5%) resistor (the "SIGNAL LEVEL" control) is internally connected directly across these terminals (see FIG. 2).

It is assumed here that the reference channel is set up and operating in the desired mode and at the correct frequency (see "REFERENCE CHANNEL" section above). Connect the output of the signal source to the "SIGNAL INPUT" terminals and with the reference channel operating, set the "SIGNAL LEVEL" switch to "OFF" and the "METER/MONITOR" switch to "SIG." Adjust the signal source so that it is producing a signal of the desired frequency and phase. Turn the "SIGNAL LEVEL" control clockwise until a reading is obtained on the panel meter. Adjust the "FREQ. TRIM" control so as to maximize this reading. Set "SIGNAL LEVEL" control so as to obtain about ½ scale reading with the "FREQ. TRIM" so adjusted. Advance the "SIGNAL LEVEL" control one position clockwise. The meter should deflect to at least full scale; if it does not, it means the total signal level is high enough to drive the signal channel tuned amplifier near the end of its linear range. In such a case it is necessary either to:

1. Use a lower setting of the "SIGNAL LEVEL" control with subsequent loss of sensitivity.

2. Reduce the level of the spurious components accompanying the signal by means of external filtering before applying the signal to the input terminals of the Lock-In Amplifier.

Once a satisfactory adjustment is obtained as outlined above, a final oscilloscope check is desirable. With the "METER/MONITOR" switch in the "SIG." position, the output of the signal channel tuned amplifier (points A and B in Figure 2) is available at the "MONITOR" terminals. A single-ended scope input may be connected between either red terminal and the black ground terminal. If desired, a balance input scope may be connected between the two red terminals. The waveform seen should be sinusoidal and free of any flattening or clipping on peaks. If such flattening is observed, the level in the tuned amplifier is too high and one of the two alternative procedures listed above should be followed to correct the situation.

This completes the preliminary adjustment of the signal channel.

PHASE SHIFTER:

With the signal and reference channels operating and adjusted as described above, place the "FILTER" switch in the "OFF" position and the "METER/MONITOR" switch in the "OUT X1" position. Connect an oscilloscope to the "MONITOR" terminals. (These terminals are now connected to points C and D in FIG. 2). A single-ended scope may be connected between either red terminal and the black ground terminal. A balanced scope input may be connected between the two red terminals. If the signal level has been set according to the above instructions a substantial deflection of the panel meter should be observed.

If the reading on the panel meter fluctuates wildly due to noise accompanying the input signal, turn the "FILTER" switch clockwise, thus narrowing the mixer bandwidth until the fluctuations are reduced to an acceptable level. If "in-phase" operation of the instrument is desired, rotate the "PHASE" control until maximum average deflection of the meter is obtained. If "90° out-of-phase" operation is desired, adjust the "PHASE" control so that the average reading of the meter is zero. Oscilloscope waveforms corresponding to the two cases are shown in FIG 3. These waveforms correspond to a pure sine wave signal; in a case where the signal is accompanied by noise, they may be somewhat obscured by the noise but they should be still easily recognized. These waveforms can only be observed with the "FILTER" switch in the "OFF" position. If this results in wild excursions of the panel meter, turn the "METER/MONITOR" switch to the "OFF" position while examining these waveforms.

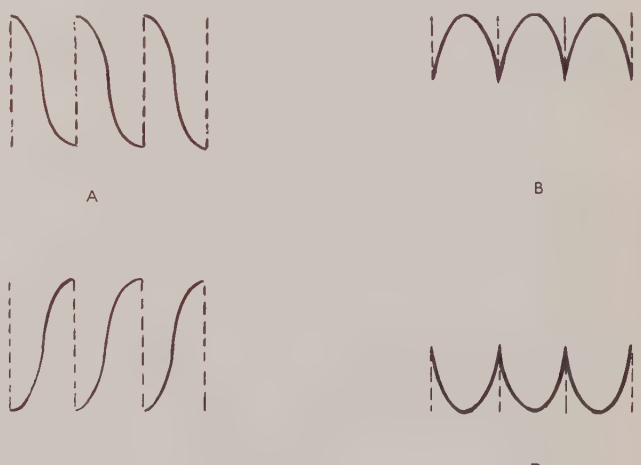


FIGURE 3

MIXER OUTPUT WAVEFORMS

A AND C (SIGNAL AND REFERENCE 90° OUT-OF-PHASE).

B AND D (SIGNAL AND REFERENCE IN-PHASE).

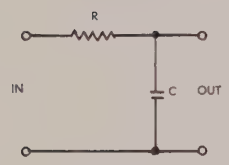
THE VERTICAL LINES REPRESENT MIXER SWITCHING TIMES.

OUTPUT FILTERING

The time constant of the output RC filtering is determined by the setting of the "FILTER" switch. Internal capacitors provide "built-in" time constants of: 0.001, 0.01, 0.1, 1, 3 and 10 seconds. Single-section or double-section RC filtering may be selected by the

"6 DB-12 DB/OCTAVE" switch. (6 db/octave corresponding to single RC and 12 db/octave to double RC filtering.)

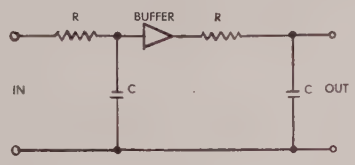
A word about the choice of single or double-section RC filtering is in order here. Figures 4A and 4B respectively show single and double-section RC filters similar to those used in the Lock-In Amplifiers.



$$\Delta B = \frac{1}{2RC}$$

$$T_r = 2.2RC$$

FIGURE 4A



$$\Delta B = \frac{1}{4RC}$$

$$T_r = 3.4RC$$

FIGURE 4B

NOTES:

1. The actual circuits look different from those in Figure 4 because of switching and the fact that they have push-pull inputs and outputs. Operationally the circuits actually used are completely equivalent to those in Figure 4.

2. The effect of the "buffer" in Figure 4B is to isolate the two sections in such a way that the second section does not load the first. In the Lock-In Amplifiers the DC amplifier plays the role of buffer.

The equivalent noise bandwidth of a single-section RC filter is given by:

$$\Delta B = \frac{1}{2RC}$$

the rise time (10% to 90%) is:

$$T_r = 2.2RC$$

For the double-section filter of figure 4B we have:

$$\Delta B = \frac{1}{4RC} \text{ and } T_r = 3.4RC$$

In comparing the two we see:

1. For a given time constant (RC) the equivalent noise bandwidth of the double-section filter is ½ that of the single-section.

2. For a given noise bandwidth, the rise time of a double-section filter is about 23% less than that of a single-section filter.

Whenever the instrument is used as a detector driving a recorder, it is clear from the above that double-section RC filtering is a distinct advantage in providing a worthwhile decrease in response time for a given noise bandwidth.

In many applications the Lock-In Amplifier is used as a component in a closed "servo loop." One criterion of stability (freedom from oscillation) of such a loop is that at no frequency shall the open loop gain roll-off as fast as 12 db/octave. In such applications the 12 db/octave position cannot be used and it is for this reason that the 6 db/octave position has been provided.

USE OF EXTERNAL CAPACITORS:

A standard octal socket is provided at the rear of the instrument to allow those needing filtering time constants longer than those available internally to obtain them by making use of external capacitors. When the "FILTER" switch is in the "EXT." position, the filter time constant is determined by capacitors wired to this socket as shown in Figure 5.

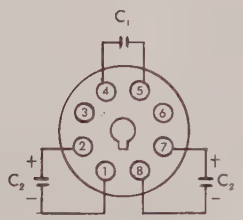


FIGURE 5A

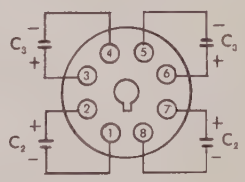


FIGURE 5B

Figure 5 shows two optional arrangements of external capacitors. The values of the capacitors for a given filtering time constant are as follows:

Capacitors	Working Voltage
C_1, 12 mfd/sec.	15
C_2, 6 mfd/sec.	15
C_3, 24 mfd/sec.	15

For example: If a 30 second time constant is desired, the following would be required:

$C_1 = 12 \times 30 = 360$ mfd.
$C_2 = 6 \times 30 = 180$ mfd.
$C_3 = 24 \times 30 = 720$ mfd.

That is, if the arrangement of Figure 5A were to be used, the capacitors required would be: 1 @ 360 mfd., 2 @ 180 mfd. If the arrangement of Figure 5B were to be used, 2 @ 180 mfd. and 2 @ 720 mfd. would be needed. The advantage of the latter arrangement is that it allows the use of all polar capacitors which, in general, are available in higher capacity values than the non-polar variety.

The performance of the instrument can be seriously impaired by leakage in these capacitors. For this reason capacitor types other than those listed below should not be used.

POLAR: tantalum electrolytic.

NON-POLAR: tantalum electrolytic, paper, oiled paper, polystyrene film, mylar film.

For all practical purposes, because of the high capacities required, the choice is limited to tantalum electrolytics. electrolytics.

With either of the arrangements shown in Figure 5, 6 db/octave or 12 db/octave filtering is available, depending on the setting of the "6 DB - 12 DB/OCTAVE" switch. If only 6 db/octave is required, omit C_1 in Figure 5A or C_3 in Figure 5B.

FINAL ADJUSTMENT (USE OF OVERLOAD INDICATOR):

The adjustments described above having been made, the instrument is essentially ready for operation. All that remains is to set the "FILTER" switch for the desired output bandwidth and to adjust the "SIGNAL LEVEL" control for the desired output level. The latter adjustment must be made with care so as not to produce an overload condition in the mixer.

If the mixer is over-driven, noise signals at its input will contribute to its output which would not otherwise do so. In general, to obtain maximum possible output from the instrument in a given situation the "SIGNAL LEVEL" control should be advanced until the "OVERLOAD" indicator glows and then backed off one step; the instrument then being operated with the "SIGNAL LEVEL" control in this position. In any case, as long as the "OVERLOAD" indicator does not glow you can be content that the mixer is not being over-driven. The "OVERLOAD" indicator circuit has been designed so that the light will come on before a serious overload condition exists.

At this point a final oscilloscope check of the waveform at the output of the signal channel tuned amplifier is desirable in order to check for an overloaded condition in this amplifier. Any peak flattening of this waveform means the signal channel level must be reduced (see "SIGNAL CHANNEL" section).

Avoiding non-linearity due to overload is a prerequisite to satisfactory operation of this (or any other) Lock-In-Amplifier. The three possible overload conditions are summarized below:

1. SIGNAL CHANNEL: discussed above and in "SIGNAL CHANNEL" section.

2. MIXER: discussed above.

3. OUTPUT DC AMPLIFIER: An over-loaded condition of the output DC amplifier is indicated by an off-scale reading of the panel meter with the "METER MONITOR" switch in the "OUT X1" position. The "cure" is simply to reduce the signal level by means of the "SIGNAL LEVEL" control.

RECORDER OPERATION:

If a galvanometer type recorder such as the Esterline Angus or the Texas Instruments Recti/riter is to be used it should be connected to the two red "OUTPUT" binding posts. The Lock-In Amplifier will drive any such recorder of 1 ma sensitivity with a coil resistance of less than 2K.

Two modes of operation are provided for such recorders; "left-hand zero" operation and "center zero" operation. A toggle switch located on the rear of the instrument selects the desired mode, and a screwdriver-adjust potentiometer, also located on the back of the instrument allows the recorder to be adjusted to agree with the panel meter.

LEFT-HAND ZERO OPERATION:

In this mode of operation the recorder pen lies at the left-hand edge of the chart when the panel meter reads zero[1] and at the right-hand edge when the panel meter reads full scale.[1] If such operation is desired, the set-up is as follows: First set the recorder pen at the left-hand chart edge by means of the mechanical zero-adjuster on the recorder. Set the "METER/MONITOR" switch to the "OUT X1" position and connect the recorder to the two red "OUTPUT" terminals. Adjust the "ZERO" control on the instrument so that the panel meter reads zero. Put the toggle switch on the rear of the instrument in the "1 ma" position, (up). Apply an input signal to the instrument and adjust its amplitude so that the panel meter reads full scale. (If the recorder does not deflect in the same direction as the panel meter, reverse its connections at the "OUTPUT" terminals). Rotate the "F. S. ADJUST" pot (also on the rear of the instruments) until the recorder also reads full scale.

CENTER ZERO OPERATION:

In this mode of operation the recorder pen lies at the center of the chart when the panel meter reads zero[1], and at the $\begin{pmatrix} \text{left} \\ \text{right} \end{pmatrix}$ edge of the chart when the panel meter reads $\begin{pmatrix} - \\ + \end{pmatrix}$ full scale.[1] If such operation is desired, set the recorder pen to the center of the chart by means of the mechanical zero-adjuster on the recorder. Set the toggle switch on the rear of the instrument to the "½ ma" position (down) and proceed as outlined in the preceding section.

OPERATION WITH ESTERLINE-ANGUS RECTILINEAR RECORDER:

This is a 1 milliamp full scale recorder with an internal resistance of about 6K. It may be used with these instruments but not quite as conveniently as the 1.5K type.

---

[1] With the "METER/MONITOR" switch in the "OUT X1" position.

CENTER ZERO OPERATION: Follow the instructions for "CENTER ZERO OPERATION" above with the exception that the rear panel toggle switch must be placed in the "1 ma" (up) position.

LEFT-HAND ZERO OPERATION: Use the mechanical zero adjuster on the recorder to set the pen at the left-hand edge of the chart at zero input. With the "METER/MONITOR" switch in the "OFF" or "OUT X1" position, plug the recorder into the two red "MONITOR" terminals. When the recorder reads full scale the panel meter will read somewhat off-scale[1]. (This will **not** damage the panel meter.)

There is no way to make the panel meter track the recorder under these conditions except by changing the meter resistors inside the Lock-In Amplifier.

RECORDER OPERATION, SERVO TYPE:

Recorders of this type are voltage rather than current measuring devices. Thus it is necessary to convert the current output of the Lock-In Amplifier into a voltage output whose range is suited to the recorder being used. These recorders are available either with single-ended (one input terminal grounded) or push-pull (floating) inputs. The latter are somewhat more compatible with these instruments.

PUSH-PULL INPUT TYPES:

When the panel meter (in the "OUT X1" or "OUT X10" position of the "METER/MONITOR" switch) reads zero, the two red "OUTPUT" terminals are at the same potential (−6V relative to chassis ground). A push-pull input recorder thus must be able to withstand a −6V common mode level at its input terminals (see recorder instruction manual). If this voltage (−6V) exceeds the common mode rating of the recorder it would be best to ground one of its input terminals and treat it as a single-ended recorder (see following section). If the recorder has this degree of common mode rejection, proceed as follows: connect a resistor (preferably wirewound) across the input terminals of the recorder whose resistance R, in ohms is given by:

$$10^{-3}\ R = E_{F.S.}$$

where $E_{F.S.}$ is the voltage required at the input to the recorder to obtain a full scale deflection of the pen. If the recorder is now connected to the "OUTPUT" terminals the set-up instructions given in the preceding section for galvanometer type recorders may be followed exactly. This will work with any recorder of this type having a full scale sensitivity of 2V. or less.

SINGLE-ENDED INPUT TYPES:

In most cases it will be possible to simply "float" the recorder on the Lock-In Amplifier output. To do this, connect the ground terminal of the recorder to one of the "OUTPUT" terminals, and the recorder input terminal to the other. THERE MUST BE NO CONNECTION BETWEEN THE RECORDER CHASSIS AND THE LOCK-IN AMPLIFIER CHASSIS. If the recorder has a 3 wire line cord an isolating adapter must be used. Connect a resistor whose value is obtained from the equation in the preceding section across the recorder input terminals and proceed as described in that section.

With some recorders using 60 cycle choppers, trouble may be encountered under these conditions due to 60 cycle pick-up. Usually this can be cured by connecting a one microfarad or larger capacitor between the Lock-In Amplifier chassis and the recorder chassis. (If an electrolytic capacitor is used, observe polarity; recorder chassis is at −6V relative to the Lock-In Amplifier chassis). If this fails to clear up the trouble (also try reversing recorder line plug in socket), then the procedure outlined below must be used.

Should "floating" operation not be possible then the following technique must be employed (see Figure 6).

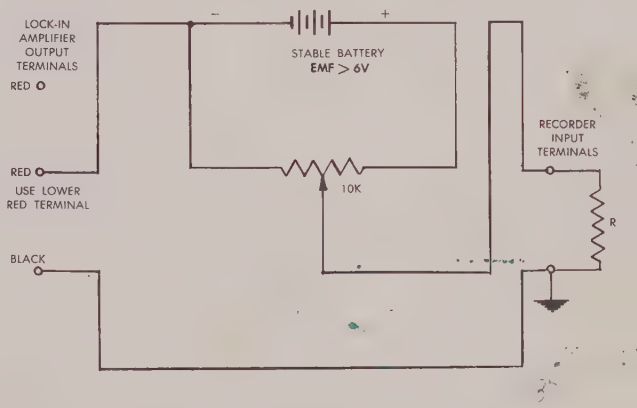


FIGURE 6

NOTE: Use **lower** red output terminal. In this case "1ma/1/2ma" switch will not affect recorder operation.

The 10K potentiometer is adjusted until the panel meter indicates zero when the recorder also indicates zero. (Left-hand, right-hand or center zero may be used for recorder). R is then adjusted so that when the panel meter reads full scale, the recorder also indicates full scale. The value of R for center zero operation will be different (about ½) from that required for left or right-hand zero operation. It is recommended that mercury cells be used to establish the 6V "bucking potential."

Some single-ended recorders have considerable "zero suppression" built-in. This is usually expressed as a multiple of full scale. (e.g. 10 × full scale). If sufficient zero suppression is available the somewhat simpler arrangement shown below can be used (Fig. 7).

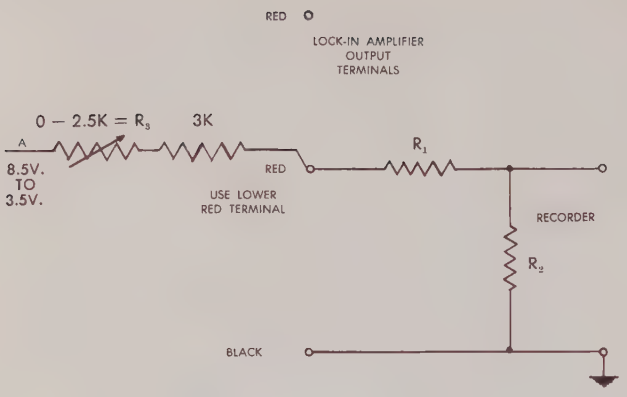


FIGURE 7

Let $E_{Z.S.}$ be the maximum recorder zero suppression and $E_{F.S.}$ be the recorder full scale voltage. A voltage divider, consisting of R_1, R_2 and the 3K and 2.5K resistors inside the Lock-In is set up at its output. Since the DC level at the point A in FIG. 7 is –6V, when the panel meter indicates zero, if the resulting DC level at the recorder is to be within its range of zero suppression then we must have:

$$6X\frac{R_2}{R_3+3K+R_1+R_2} = 6\lambda = E_{Z.S.} \text{ where:}$$

$$\lambda = \frac{R_2}{R_3+3K+R_1+R_2}$$

If full scale on the panel meter is to correspond to full scale on the recorder we must have:

$$2.5\,\lambda = E_{F.S.}$$

$$\text{i.e. } \lambda = \frac{E_{F.S.}}{2.5}$$

$$\text{and hence: } \frac{6}{2.5} = \frac{E_{Z.S.}}{E_{F.S.}}$$

thus, if the zero suppression built into the recorder is $\frac{6}{2.5} = 2.4$ times full scale or better, it can be used in this way. R_3, which is the "RECORDER ADJUST" potentiometer located on the back of the Lock-In, may be used for fine adjustment of full scale.

TO DETECT SIGNALS AT HARMONICS OF SOME BASIC REFERENCE FREQUENCY

In some Lock-In Amplifier applications the signal appears at a harmonic of the basic reference frequency. In such a case the Lock-In Amplifier must be operated at this harmonic frequency. The JB-4 and JB-5 are ideally suited to this sort of operation due to their continuously tunable reference channel tuned amplifiers. In general, the reference signal (assumed to be sinusoidal) is fed into a simple harmonic generator, the desired harmonic being selected by means of the tuned amplifier.

If even (2nd and higher) harmonics are of interest, the following harmonic generator is useful:

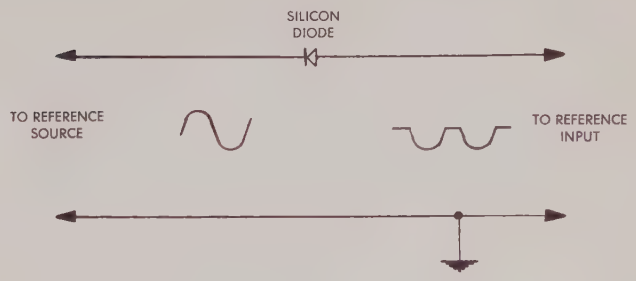


FIGURE 8

The amplitude of the reference sine wave should be several volts peak to obtain efficient rectification.

The Fourier Series of an ideal waveform of this type is:

$$E(t) = E_0\left[\frac{1}{\pi} + \frac{1}{2}\sin\omega t - \frac{2}{\pi}\sum_{k=2}^{\infty}\frac{\cos k\omega t}{k^2-1}\right] (k \text{ even})$$

where E(t) is the output waveform of the half wave rectifier and E_0 is the peak value of the input voltage. Apart from the fundamental, the output contains only even harmonics, the amplitude of the $2n^{th}$ harmonic being:

$$A_{2n} = \frac{2}{\pi}E_0\frac{1}{4n^2-1}$$

and for the second harmonic n = 1, therefore $A_2 = \frac{2E_0}{3\pi}$

For operation in the "SEL. EXT." mode a minimum level (of the desired harmonic) of 100 millivolts peak-to-peak is required at the reference input terminals, i.e., we must have

$$2A_2 \geq 100 \text{ mv.}$$

$$\text{i.e. } \frac{4E_0}{3\pi} \geq 100 \text{ mv.}$$

$$E_0 \geq \frac{100\times 3\pi}{4} \approx 235 \text{ mv.}$$

Since this is below the minimum value for efficient rectification by a silicon diode it is clear that any reference voltage large enough to produce the output waveform of Figure 8 will be adequate to drive the Lock-In Amplifier.

For second harmonic operation, simply feed the reference signal to the Lock-In via a diode as shown in Figure 8. Set the "FREQUENCY" dial and "FREQUENCY RANGE" switch to the second harmonic of the reference frequency and proceed as described in the "SELECTIVE EXTERNAL"

mode section of "OPERATING INSTRUCTIONS" in this manual.

Operation on "even" harmonics higher than the second is possible. The following considerations should be understood before such operation is attempted.

The reference channel tuned amplifier at full gain "1" can withstand an input of at least 1 V peak-to-peak and still maintain its normal selectivity characteristic. In order to assure proper operation, the maximum instantaneous peak input voltage must be kept below this level. (Of course for settings of the "REFERENCE LEVEL" control other than "1" this limiting value is proportionately higher). If a high order harmonic is used, the level of the harmonic of interest will be considerably lower than the maximum instantaneous peak input level (E_0). If we assign a maximum value of 1 to E_0 then the peak value of the $2n^{th}$ harmonic is:

$$A_{2n} = \frac{2}{\pi}\frac{1}{4n^2-1} \geqq 50\ mV$$

This gives a maximum value for n of 2. i.e., this method will allow operation on even harmonics up to the 4th. For still higher even harmonics the circuit in Fig. 9 can be used.

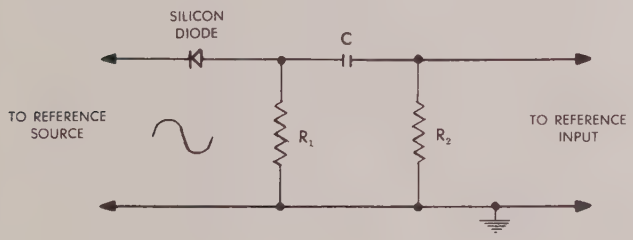


FIGURE 9

R_2 and C constitute a high-pass filter whose effect is to reduce the level of the lower order harmonics. A good choice for R_2C is a value such that

$$\omega_n = \frac{1}{R_2C}$$

where ω_n is the angular frequency of the desired harmonic. Of course more elaborate preselection methods may be used.

In any case, the Lock-In is set to the frequency of the desired harmonic and set up as outlined in the "SELECTIVE EXTERNAL" section of "OPERATING PROCEDURE" in this manual.

If odd (3rd and higher) harmonic operation is desired, the following circuit can be used (Figure 10).

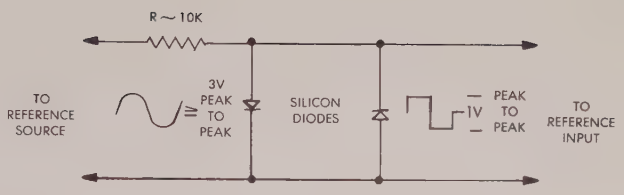


FIGURE 10

The resulting waveform has a harmonic structure given closely by:

$$E(t) = \frac{4E_0}{\pi}\sum_{k=0}^{\infty}(-1)^k\ \frac{\cos(2k+1)\omega t}{2k+1}$$

where E_0 is about ½ volt for silicon diodes. Using an argument similar to that of the preceding section, it turns out that this arrangement will permit operation up to the 5th harmonic.

If operation at higher odd harmonics is desired, the following circuit may be used.

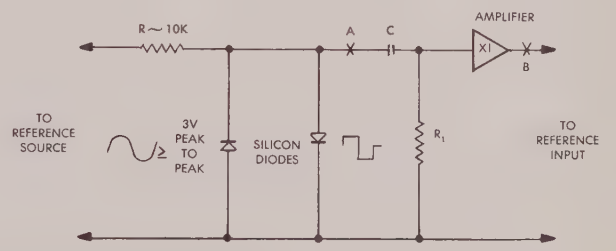


FIGURE 11

If $R_1C = \frac{1}{\omega_n}$ the voltage gain from A to B at a frequency ω_n will be approximately 0.7. At frequencies ω, below ω_n the gain is roughly proportional to ω. The amplitude of the harmonics in the input waveform, however, is proportional to $\frac{1}{\omega}$. Therefore up to ω_n the various odd harmonics appearing at B are all about the same amplitude. If ω_n is chosen to be the highest harmonic of interest then operation at all odd harmonics below this will be possible.

In any case, the Lock-In is tuned to the harmonic of interest and set up according to the procedure in the "SELECTIVE EXTERNAL" section of "OPERATING INSTRUCTIONS" in this manual.

CIRCUIT DESCRIPTION

INTRODUCTION:

The various circuit elements that go together to make up this instrument are assembled on five plug-in printed circuit boards and one printed circuit board mounted on the front panel. The distribution is as follows: (the identification nos. referred to appear on the printed wiring side of the boards).

Plug-in Board No. TA0209A, SIGNAL CHANNEL TUNED AMPLIFIER.

Plug-in Board No. TA0209B, REFERENCE CHANNEL TUNED AMPLIFIER.

Plug-in Board No. PS0112A, PHASE SHIFTER AND AC VOLTMETER.

Plug-in Board No. MO797, MIXER AND DC AMPLIFIER.

Plug-in Board No. P0114, POWER SUPPLY.

Board No. OE0311, "ODDS AND ENDS."

Access to these boards may be had by removing the back panel of the instrument. They are located as shown in FIG. 12 which is a back view with the rear cover removed.

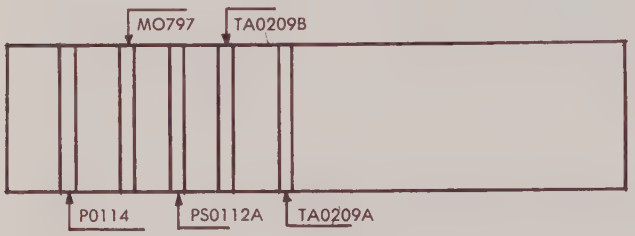


FIGURE 12

The circuitry will be described board by board in order to assist those with the task of troubleshooting the unit and those users who wish to understand the principles of its operation.

PHASE SHIFTER (BOARD NO. PS0112A):

The continuously variable phase-shifter used in this instrument is based on the following circuit:

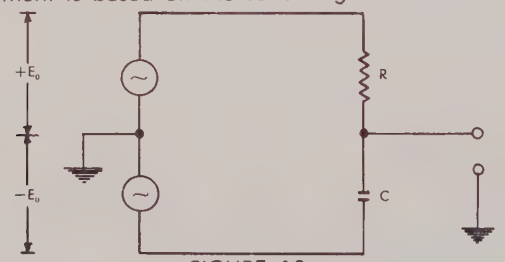


FIGURE 13

A series RC combination is driven from a push-pull voltage source whose output is $2E_0$ volts. The output is taken between the RC junction and ground as shown. Upon analysis of this circuit one obtains the result that the output voltage is E_0, independent of R, C and the angular driving frequency ω. The phase-angle ϕ of the output voltage is given by:

$$\phi = 2\text{Tan}^{-1}\omega RC$$

The phase-shifter employed in this instrument consists of a cascade of two such elements. The basic circuit of a single element is as shown in FIG. 14.

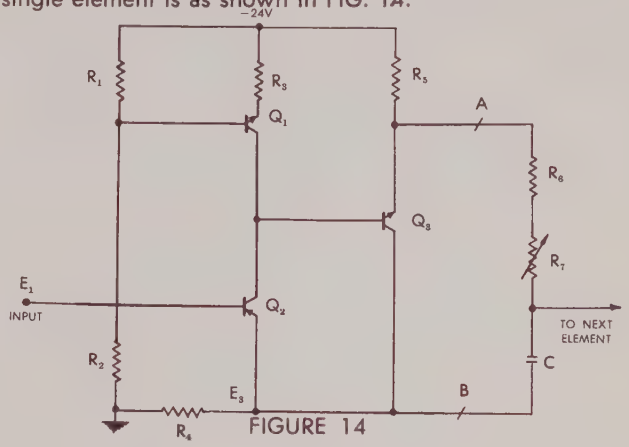


FIGURE 14

Q_1 is a current source for the collector of Q_2. This current is set by the voltage across R_3, which is determined by R_1 and R_2. Because the collector of Q_1 represents a very high impedance compared to the base of Q_3, essentially all of the signal current generated in the collector circuit of Q_2 due to an input voltage E_1 flows into the base of Q_3. The resulting signal current in the emitter of Q_3 flows into R_5, that in the collector flows into R_4, (assuming for the moment that the load is disconnected at points A and B). If $^ic_3$ is the signal collector current, and $^ie_3$ the signal emitter current in Q_3, then very nearly,

$$^ic_3 = \alpha_3\, ^ie_3$$

where α_3 is the grounded base forward current transfer ratio of Q_3 and thus $^iR_5$ the signal current in R_5 is given by:

$$^iR_5 = \frac{1}{\alpha_3}\, ^ic_3$$

The signal current flowing in R_4 is: $^ic_3 + ^ie_2$ where $^ie_2$ is the signal emitter current of Q_2. Now we have:

$$^ie_2 \approx \frac{1}{\beta_3}\, ^ic_3$$

where β_3 is the common emitter forward current transfer ratio of Q_3, i.e. the current in R_4 is:

$$^iR_4 \approx {}^ic_3 \times (1 + \frac{1}{\beta_3}) = \frac{1}{\alpha_3}\, ^ic_3$$

Therefore, $^iR_4 \approx {}^iR_5$ and the signal currents in R_4 and R_5 are very nearly equal. Thus:

$$\frac{E_2}{E_3} \approx \frac{R_4}{R_5}$$

and for $R_4 = R_5$ these voltages are equal in magnitude and opposite in phase. Since further, $\frac{E_1}{E_3} = 1$, this circuit is a unity-gain phase-splitter. The effect of connecting

the phase-shift network (R_6, R_7, and C) at A and B is to place an impedance $\frac{Z}{2}$ (where Z is the impedance of R_6 and R_7 in series with C) in parallel with each of R_4 and R_5 and no unbalance is produced. Thus the conditions assumed in deriving the behavior of the phase-shift network are met by this circuit. Furthermore, because of the large amount of negative feedback employed in the phase-splitter these conditions are held closely over the range of frequencies and impedances (Z) encountered in the operation of the instrument.

Actual circuit values of the various components used are shown on the schematic diagram for this board. The capacitors C are determined by the position of "FREQ. RANGE" switch.

Q_{307} on the schematic diagram functions as an output phase-splitter, giving two 180° out of phase outputs either of which is selected by the "INVERT" switch. A word of explanation on the role of C_{302} and R_{305} is in order.

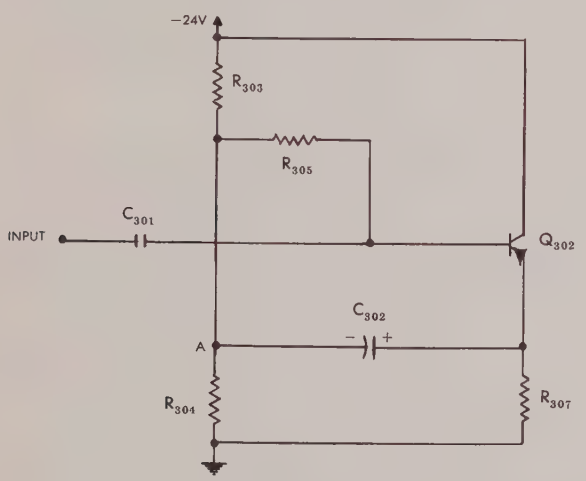


FIGURE 15

C_{302} (see FIG. 15 and schematic diagram) has the effect of making the signal voltage at the emitter of Q_{302} appear also at point A. If e_b is the signal voltage on the base of Q_{302} the voltage thus impressed on point A will be Ke_b where K is typically $\approx$ 0.98. Thus the voltage R_{305} will be:

$$E_R = e_b - Ke_b \approx 0.02\, e_b$$

i.e. the signal current flowing into R_{305} will be about 1/50 of what it would be without C_{302}. Thus it gives R_{305} an effective value $\approx$ 500 K and greatly increases the AC impedance at the base of Q_{302}. This circuit is used elsewhere in the instrument to increase input impedance.

The component values in the phase-shifter elements themselves are chosen so that more than 180° of continuously variable phase-shift is provided at any frequency within the range of the instrument. Thus, by making use of the "INVERT" switch any desired phase angle may be set between the signal and reference channels.

AC VOLTMETER/AMPLIFIER (BOARD NO. PS0112):

The input of the peak-to-peak voltmeter circuit is point V2 (see phase shifter board schematic diagram), its output being point W1. If a sine wave of E volts peak-to-peak swinging about any DC reference level is applied to V2, C_{305} will, due to the action of D_{301}, charge until the base voltage of Q_{312} swings as shown in FIGURE 16.

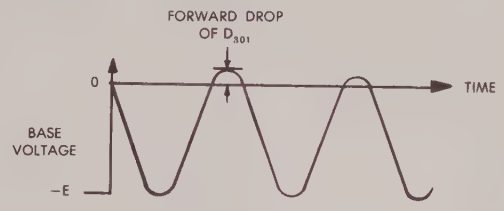


FIGURE 16

The voltage at the junction of R_{328}, and R_{329} will be as shown in FIG. 17.

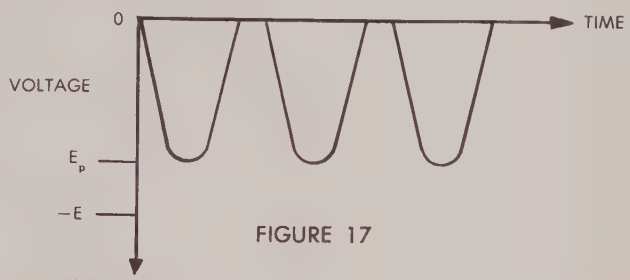


FIGURE 17

E_p will be given by:

$E_p = E$ − (forward drop D_{301} + base emitter drop Q_{312}).

The DC average of this waveform will appear across C_{306}. This DC voltage is thus a function of the peak-to-peak voltage of the input waveform. This voltage is indicated by the panel meter in the "SIG." and "REF." positions of the "METER/MONITOR" switch.

In the "REF." position of the "METER/MONITOR" switch (see chassis wiring diagram) point V2 is connected to phase-shifter output point P2. The AC voltage normally appearing at this point is about 5V. peak-to-peak. This voltage applied to V2 will produce, at W1, a DC voltage of about 1.5V as indicated by a meter with an impedance large compared to 22K.

In the "SIG." position of the METER/MONITOR" switch (see chassis wiring diagram) point V2 is connected to the output of the meter amplifier (W2). The input to this amplifier is then connected to output point O2, (see signal channel tuned amplifier schematic diagram) of the signal channel tuned amplifier. Since the nominal level at this point is of the order of 60 mv peak-to-peak, the amplifier is needed to bring the level of the input to the voltmeter circuit up to $\approx$ 5V. peak-to-peak. This amplifier uses the same circuit as that shown in FIG. 14 and the description accompanying FIG. 14 describes the operation of this amplifier as well. In this case however the ratio of the emitter resistors (R_{324}/R_{323}) is 100 instead of unity, and as a result this amplifier has (from V1 to W2) a gain of 100.

TUNED AMPLIFIER (BOARD NOS. TA0209A AND TA0209B):

If one studies the schematic diagram for these boards it will be evident that these two (reference channel and signal channel) tuned amplifiers are identical except for a few specific component values, and their nominal supply voltages. The different supply voltages are due to extra filtering and regulation being used on the voltage supply to the signal channel in order to reduce its ripple and to eliminate possible coupling to the reference channel via the power supply. Consequently this description will be made in terms of the reference channel unit, with the understanding that it applies to both.

The tuned amplifiers are based on the resonant transfer function of the following circuit:

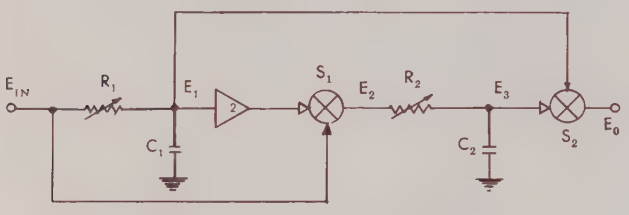


FIGURE 18

$$\frac{E_1}{E_{in}} = \frac{1}{1+j\omega R_1C_1}$$

$$\frac{E_2}{E_{in}} = \frac{E_{in} - 2E_1}{E_{in}} = 1 - \frac{2}{1 + j\omega R_1C_1} = \frac{-1 + j\omega R_1C_1}{1 + j\omega R_1C_1}$$

$$\frac{E_3}{E_{in}} = \frac{E_2}{E_{in}} \times \frac{1}{1 + j\omega R_2C_2} = \frac{-1 + j\omega R_1C_1}{(1 + j\omega R_1C_1)(1 + j\omega R_2C_2)}$$

$$\frac{E_0}{E_{in}} = \frac{E_3 + E_1}{E_{in}}$$

$$= \frac{-1 + j\omega R_1C_1}{(1 + j\omega R_1C_1)(1 + j\omega R_2C_2)} + \frac{1 + j\omega R_2C_2}{(1 + j\omega R_1C_1)(1 + j\omega R_2C_2)}$$

$$= \frac{j\omega(R_1C_1 + R_2C_2)}{1 - \omega^2R_1C_1R_2C_2 + j\omega(R_1C_1 + R_2C_2)} \quad \ldots\ldots\ldots 1$$

The normalized current in a series RLC resonant circuit is given by:

$$\frac{i}{i_0} = \frac{j\frac{\omega}{Q_0\omega_0}}{1 - \left(\frac{\omega}{\omega_0}\right)^2 + j\frac{\omega}{Q_0\omega_0}}$$

where $\omega_0 = \frac{1}{\sqrt{LC}}$ $\quad Q_0 = \frac{\omega_0 L}{R}$ $\quad i_0 = \frac{E}{R}$

Equation 1 is of the same form as the equation for $\frac{i}{i_0}$

where:

$$\omega_0 = \frac{1}{\sqrt{R_2C_2R_1C_1}} \text{ and } Q_0 = \frac{\sqrt{R_2C_2R_1C_1}}{R_1C_1 + R_2C_2}$$

If we define $R = \sqrt{R_1R_2}$ $\quad C = \sqrt{C_1C_2}$

and let $R_1 = aR$ $\quad C_1 = bC$

$R_2 = R/a$ $\quad C_2 = C/b$

Then $\omega_0 = \frac{1}{RC}$; $\quad Q_0 = \frac{1}{ab + \frac{1}{ab}} = \frac{ab}{1 + (ab)^2}$

Note, however, that the transfer function is unity at resonance, independent of the values of "a" and "b." In practice, the capacitors have nominally the same value with a tolerance of 5%, so "b" lies within $1 \pm .05$; tolerances (including tracking) on the R's are similar. The effect on Q_0 is completely negligible: if $ab = 1 + \delta$, then

$$Q_0 \approx \frac{1}{2}\left[1 - \frac{\delta^2}{2}\right]$$

and for $\delta \approx .1$, the Q_0 differs from the maximum value by only ½%.

The actual circuit follows the block diagram of FIG. 18 closely except for a phase inversion right at the input and a liberal use of current sources in place of voltage sources (See Schematic Diagram). Let us take the base of Q_{203} as our input point. Any voltage E_{in} appearing there is transmitted to the base of Q_{205}, which then is a source of current

$$i_1 = \frac{-E_{in}}{R_{213}}$$

This current flowing in R_{214} produces a voltage

$$i_1R_{214} = -E_{in}\frac{R_{214}}{R_{213}} \approx -E_{in}$$

with a source impedance equal to R_{214}; this resistor is thus a part of the frequency determining RC network. The voltage appearing at the base of Q_{209} is then the E_1 of the block diagram except for a sign change. This voltage is also applied (through the emitter followers Q_{209} and Q_{211}) to the base of Q_{204}, which provides the gain of −2. It also acts as the (current) summing junction S_1, accepting a current $-E_{in}/R_{210}$ from Q_{203}. The summed currents flowing in R_{215} produce (−) E_2, and the base of Q_{206} receives (−) E_3.

The voltages which must finally be summed thus appear at the bases of Q_{206} and Q_{209}. To keep loading to a minimum, the impedances at these points must be as high as possible. This is accomplished by means of the additional current gain provided by Q_{207} and Q_{208}; this sum current is equivalent to the output in the block diagram of FIG. 18.

Finally, the Q must be raised from ½ to the desired value of 25. This is accomplished by means of the following positive feedback network:

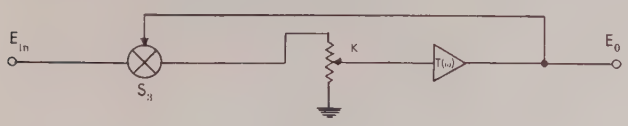


FIGURE 19

The transfer function T(ω) is the one generated above:

$$T(\omega) = \frac{j\frac{\omega}{Q_0\omega_0}}{1 - \left(\frac{\omega}{\omega_0}\right)^2 + j\frac{\omega}{Q_0\omega_0}}$$

Solving the loop equation, we find

$$K(\omega) = \frac{e_0}{e^{in}} = \frac{kT(\omega)}{1 - kT(\omega)} = \frac{kj\frac{\omega}{Q_0\omega_0}}{1 - \left(\frac{\omega}{\omega_0}\right)^2 + j\frac{\omega}{Q_0\omega_0} - kj\frac{\omega}{Q_0\omega_0}}$$

$$= \frac{k}{1-k} \; \frac{j\frac{\omega}{\omega_0}\frac{1-k}{Q_0}}{1 - \left(\frac{\omega}{\omega_0}\right)^2 + j\left(\frac{\omega}{\omega_0}\right)\frac{1-k}{Q_0}}$$

Thus $\left| K(\omega) \right|_{max} = k/(1-k)$; $Q_{eff} = \frac{Q_0}{1-k}$

To make $Q_{eff} = 25$, we need $1 - k = \frac{1}{50}$, or $k = .98$ and $K = 49 \approx 2\,Q_{eff}$

In the actual circuit, the input transistor, Q_{202}, operates in the same basic way as the input transistor in the phase shifter. The output current of this transistor is added to the output current of the frequency selective network at the emitter of Q_{201}, which thus serves as the summing junction S_3 of FIG. 19. The Q adjustment is then provided in R_{206}, which sets the k of FIG. 19.

Since the output of the frequency selective network does not appear as a voltage until it has already been added to the input at R_{206}, it is necessary to duplicate the summing junction S_2 (FIG. 18) for the final output. This is done by means of Q_{210} and Q_{211}, whose currents are summed at Q_{212} and sent to R_{223}. This signal then drives the split-load phase inverter Q_{213} which provides the push-pull output for the mixer.

If the behavior of the tuned amplifier is to duplicate the behavior of an RLC tuned circuit exactly, it is necessary that the output of the tuned amplifier go to zero at frequencies far above and far below the resonant frequency. From FIG. 18 it is clear that since both E_1 and E_3 approach zero at high frequencies due to the action of C_1 and C_2, and since $E_0 = E_1 + E_3$ there will be no output at these frequencies. At very low frequencies C_1 and C_2 may be neglected and we have

$$E_1 = E_{in}$$
$$E_2 = E_{in} - 2E_{in} = -E_{in}$$
$$\text{and } E_3 = E_2 = E_{in}$$
$$\therefore \; E_1 = -E_3 = 0$$

and once again there is no output. This last case depends on the gain of the amplifier preceding S_1 being exactly −2. R_{211}, the "LOW FREQUENCY BALANCE" adjustment enables this gain to be so adjusted.

MIXER, DC AMPLIFIER (BOARD NO. M0797):

(Refer to schematic diagram.) The mixer proper consists of Q_{401} through Q_{406} and their associated components. The points marked α and β are driven 180° out-of-phase by a square wave at the reference frequency. They swing from approximately −16V to −14V relative to ground. Q_{403} and Q_{406} function as current sources, their collector currents being proportional to the instantaneous signal levels at M_1 and M_2. Assume for the moment that no signal is applied at M_1 and M_2. In this case the DC collector currents of Q_{403} and Q_{406} are determined by the bias string (R_{401}, R_{404}) and their respective emitter resistors. Consider what happens during the half cycle when point α is at −14V and β is at −16V. The emitters of Q_{401} and Q_{405} will be held at about −14.5V, along wtih the emitter of Q_{402} and Q_{404}. Since the bases of Q_{402} and Q_{404} are thus at −1.5V relative to their emitters, these transistors will be cut-off. As a result, the collector current of Q_{403} will flow into R_{405} and that of Q_{406} will flow through R_{411}, the voltage drop across these resistors being determined by their respective currents. On the next half cycle the situation is reversed, Q_{403} feeding R_{411}, Q_{406} feeding R_{405}. In general the quiescent DC collector currents of Q_{403} and Q_{406} will not be the same and as a result the voltage across R_{405} and R_{411} will change each half cycle. The result will be a reference frequency square wave at these two points. If R_{408} and R_{409} are adjusted to equalize these currents, the square wave will disappear. If an AC input signal is now applied between M_1 and M_2 the resulting AC collector currents in Q_{403} and Q_{406} will be switched between R_{405} and R_{411} in just the way described above. Thus the mixer functions as a double-pole double-throw switch, being driven at the reference frequency. If a sine wave at the reference frequency and in phase with it is applied to the mixer input, the output waveform will appear as shown in FIG. 20.

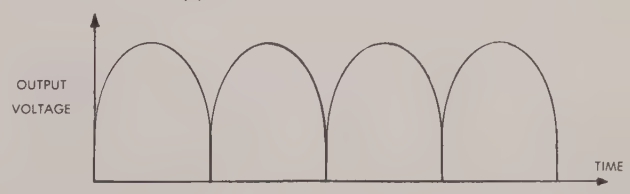


FIGURE 20

The mixer is followed by a conventional balanced DC amplifier consisting of Q_{407} through Q_{413} and their associated components. (Components enclosed in dashed lines are not on the board; see chassis wiring diagram.)

OVERLOAD INDICATOR:

The utility of a coherent detector of this type in recovering a signal from noise is due to the fact that of the total spectrum (signal-plus-noise) applied to its input, only the signal plus whatever of the noise lies within a bandwidth determined by the output filtering about the signal frequency contributes to the detector output. In order for this to be true if is necessary that the output of the mixer be a linear function of its input. If this is not the case, noise lying outside the bandwidth interval discussed above will contribute to the mixer output through cross-modulation ("noise beating with noise") and other effects; the result being to degrade the signal-to-noise at the mixer output. Since non-linearity will result from mixer overload, it is important to prevent this from occurring.

In the Lock-In Amplifier, an overloaded condition at the mixer output will be indicated by an off-scale reading of the panel meter in the "OUT XI" position of the "METER/MONITOR" switch. If this were the only possible mixer overload condition, overload prevention would consist merely of monitoring the panel meter. However in an application where the signal-to-noise ratio at the mixer input is poor, with a long time constant being used, it is possible that the mixer is being over-driven even though the output signal is quite small. The reason being that under these conditions (poor signal-to-noise) the part of the mixer input spectrum which determines the mixer output (signal-plus-noise close to signal frequency) contributes only a small fraction to the level at the mixer input. Thus the level (signal-plus-noise) at the mixer input can be sufficient to overload it even though the mixer output is small. It is an overload condition of this type that is indicated by the "OVERLOAD" light.

The operation of the "OVERLOAD" light is based on the behavior of the point marked "OV" (see mixer schematic diagram). The mixer operates by switching the collector currents of Q_{403} and Q_{406} alternately to R_{405} and R_{411}. The mixing will be linear as long as the collector currents of these transistors are linear functions of their base voltages. The points M_1 and M_2 are driven by the push-pull output of the signal channel tuned amplifier. Thus the voltage swings on the bases of Q_{403} and Q_{406} are equal and opposite (assuming the push-pull output of the tuned amplifier to be perfectly balanced). Under these conditions when the emitter current of one of Q_{406}, Q_{403} increases the other will decrease by just the same amount. The result is that the current in R* remains constant at its quiescent value of about 2.4 ma. When the base of either Q_{403} or Q_{406} has risen to about 0.7V above its quiescent level its emitter current will have increased 1.2 ma. above its quiescent value. At this point the other transistor will be cut-off. This represents the absolute limit of the linear range of the mixer. If the current of the conducting transistor increases beyond this point, the current through R* will change since there can now be no compensating decrease in the current of the other (cut-off) transistor.

* Because of C_{407}, R_{410} and R_{423} are connected together (AC equivalent). R is the AC equivalent circuit consisting of the parallel combination of two series branches; namely, R_{410} in series with a portion of potentiometer R_{409}, and R_{423} in series with the remaining portion of R_{409}.

As a result, when an overload of this kind occurs an AC voltage appears at "OV." After amplification this waveform is applied to the base of Q_2. When such an overload occurs, Q_2 begins to conduct, thus causing the overload light, B_3, to glow. (See FIG. 21.)

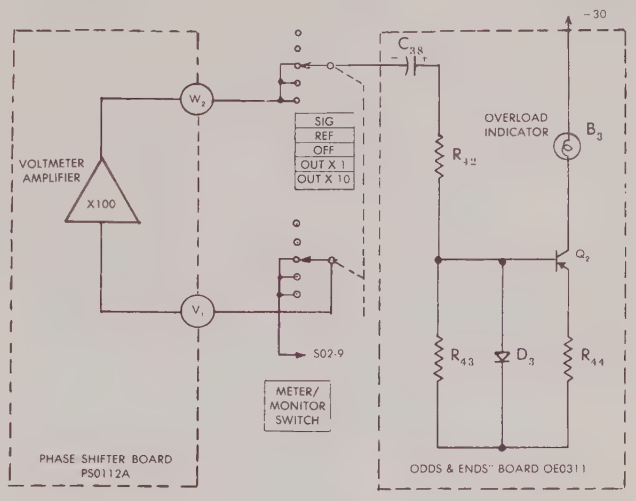


FIGURE 21

In the discussion above it was assumed that the signals applied to M_1 and M_2 were perfectly balanced. In practice this will not be the case, and the result will be that a small signal will appear at "OV" even when the mixer is operating linearly. The effect of this is to make the "OVERLOAD" indicator glow a bit prematurely. This is a "good fault" in the sense that, as a result, one may rest assured that as long as the "OVERLOAD" indicator does not glow, that the mixer is operating linearly.

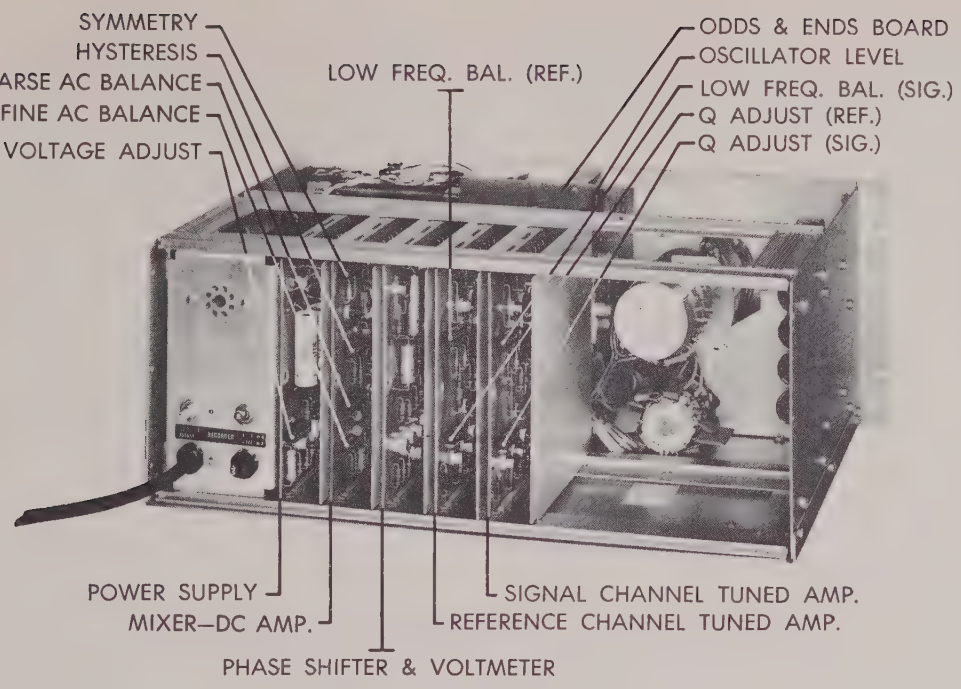
Q_{414} through Q_{416} and their associated components make up a Schmitt trigger circuit which generates the square wave to drive the mixer. Q_{417} is a driver for the Schmitt trigger circuit.

This circuitry is completely conventional and no trouble should be encountered in trouble-shooting it by anyone versed in conventional transistor circuitry.

POWER SUPPLY (BOARD NO. P0114):

This board contains the −24V and −20V regulators. The circuits are completely conventional and require no detailed discussion. The output current (about 250 ma. in normal operation) is limited by D_{508} and R_{503} to about 500 ma. under short circuit. If either supply is shorted, F501 will blow in about one minute. If trouble is encountered with the unit and F501 is found to be blown, locate the short circuit that caused it, correct it, and replace F501.

NOTE: UNDER NO CIRCUMSTANCES USE A FUSE LARGER THAN THE TYPE SPECIFIED ON THE SCHEMATIC DIAGRAM AS A REPLACEMENT FOR F501. IF AN EXCESSIVELY HIGH CURRENT FUSE WERE INSTALLED HERE A PROLONGED SHORT CIRCUIT COULD RESULT IN THE DESTRUCTION OF Q_{501}, Q_{508} OR BOTH.



SECTION V

ALIGNMENT PROCEDURE
(FILTER SWITCH MUST BE IN "OFF" POSITION FOR ALL ADJUSTMENTS)

INTRODUCTION:

Removing the back cover from the instrument by removing the 6 screws that hold it in place gives access to all the alignment adjustment points except the oscillator level adjustment. The top panel must be removed for this adjustment.

SIGNAL CHANNEL TUNED AMPLIFIER:

This board is on the extreme right as viewed from the back of the instrument. It has two alignment trimpots: "Q-ADJUST" being the lower one (R_{106}) and "LOW FREQUENCY BALANCE" the upper (R_{111}). In setting these, the "LOW FREQUENCY BALANCE" should be set first, as this adjustment affects the "Q-ADJUST." The "Q-ADJUST" has very little effect on the "LOW FREQUENCY BALANCE."

LOW FREQUENCY BALANCE (R_{111}):

This adjustment minimizes the response of the tuned amplifier to frequencies far from the resonant frequency. To adjust it, set the "METER/MONITOR" switch to "SIG.", the "SIGNAL LEVEL" switch to "1," and the "FREQUENCY" and "FREQ. RANGE" controls to give 15 Kc. Apply a signal of about 1 volt peak-to-peak at 15 to 60 cps to the signal input terminals. Adjust the "LOW FREQUENCY BALANCE" trimpot until the output seen at the monitor terminals by a detector of millivolt sensitivity is a minimum.

Q ADJUST (R_{106}):

This adjustment sets the Q of the tuned amplifier. To adjust it, set the "METER/MONITOR" switch to "SIG.", the "SIGNAL LEVEL" control to ".02," the "FREQUENCY" and FREQUENCY RANGE" controls to a frequency of 400 cycles and apply a 400 cycle sine wave of about 50 mv. peak-to-peak to the signal input terminals. Connect a scope or AC voltmeter between either of the two red monitor terminals and ground and adjust either the frequency of the applied signal or the "FREQUENCY" dial on the Lock-In Amplifier for maximum output. This having been done, vary the "Q ADJUST" control until the signal level at the "MONITOR" terminals is the same as that applied to the "SIGNAL INPUT" terminals. This sets the on-resonance gain of the tuned amplifier at 50, and since this gain is just 2Q it sets the Q at 25. The Q of both tuned amplifiers varies somewhat with frequency.* A Q of 25 may be obtained at any frequency in the range by making the adjustment described above at that frequency. If a Q value different than 25 is desired, it may be obtained by setting the gain of the tuned amplifier under these conditions to twice the desired Q value.

REFERENCE CHANNEL TUNED AMPLIFIER:

This board is located second from the right as viewed from the back of the instrument. It has the same two

* See note in Section 1.

adjustments as the signal channel tuned amplifier board, located in the same relative positions, and the adjustment procedure is the same as for the signal channel tuned amplifier board except for the differences noted below:

LOW FREQUENCY BALANCE (R_{211}):
This adjustment is made in the same way as outlined for the signal channel except that the "METER/MONITOR" switch is set to the "REF." position, "REFERENCE MODE" switch to the "SEL. EXT." postion and the input signal is applied to the "REFERENCE IN/OUT" terminals. The "MONITOR" terminals in this case are single-ended; the lower red terminal is at chassis ground.

Q ADJUST (R_{206}):
This adjustment is made in the same way as outlined for the signal channel except that the "METER/MONITOR" switch is placed in the "REF." position, the "REFERENCE MODE" switch in the "SEL. EXT." position, "REFERENCE LEVEL" control at ".02," and the input signal is applied to the "REFERENCE IN/OUT" terminals. The level of the input signal can be as much as 1V peak-to-peak. "MONITOR" terminals in this case are single-ended; the lower red terminal is at chassis ground.

PHASE SHIFTER-AC VOLTMETER BOARD:
This board is third from the right as viewed from the back of the instrument. There are no alignment adjustments on this board.

MIXER-DC AMPLIFIER BOARD:
This board is located second from the left as viewed from the back of the instrument. There are four adjustment trimpots on this board. The upper most one is the "SYMMETRY" adjustment (R_{437}), the one below that is the "HYSTERESIS" adjustment (R_{427}), the next lower one the "COARSE AC BALANCE" adjustment (R_{409}), and the lowest one the "FINE AC BALANCE" adjustment (R_{408}). These should be adjusted in the order given below:

HYSTERESIS CONTROL (R_{427}):
Turn the "SIGNAL LEVEL" control to "OFF," the "REFERENCE MODE" switch to the "EXT." position, the "METER/MONITOR" switch to "OFF" and connect an oscilloscope between the junction of either R_{426} and R_{432} or R_{429} and R_{435} on the mixer board and ground. With the "REFERENCE LEVEL" control in the "1" position apply a sine wave of about 5 volts peak-to-peak to the "REFERENCE IN/OUT terminals. Any convenient frequency between 15 cps and 15 KC may be used. Under these conditions a square wave of about 1 volt peak-to-peak should be visible on the scope. Reduce the amplitude of the sine wave applied to the "REFERENCE IN/OUT" terminals until the Schmitt trigger just stops triggering. This is evidenced by the square wave disappearing from the scope. Increase the signal level until the Schmitt trigger circuit is just barely triggering. If the square wave is very asymmetrical under these circumstances, adjust the "SYMMETRY" control until it is reasonably symmetrical. Now again reduce the level of the input signal until the Schmitt trigger just stops triggering. By varying the "HYSTERESIS" control it should be possible to get the Schmitt trigger to trigger once more. Keep reducing the signal level and readjusting the "HYSTERESIS" control until the Schmitt trigger breaks into oscillation or until its output waveform is no longer square but begins to look more like a clipped sine wave (whichever occurs first). Back off from this point until the effect disappears and then one turn further. Readjust the "SYMMETRY" adjust control so that this square wave looks reasonably symmetrical.

SYMMETRY CONTROL (R_{437}):
Before making this adjustment the "HYSTERESIS" control should be set as outlined in the preceding section. To make this adjustment two audio oscillators are required. When the duty cycle of the mixer switching waveform is exactly 50%, the response of the mixer to the second (and all other even harmonics) of the reference frequency is a minimum. The "SYMMETRY CONTROL" is provided to so adjust the switching waveform. Although this adjustment could be made by observing this waveform on a **good** scope and setting the duty cycle to 50% as indicated by the scope, the following procedure is much to be preferred since it serves to minimize the mixer's response to the second harmonic. Set the "METER/MONITOR" switch in the "REF" position, the "REFERENCE MODE" switch in "EXT." and connect one of the audio oscillators to the "REFERENCE IN/OUT" terminals. Set the oscillator frequency at about 1 KC and adjust the "REFERENCE LEVEL" control and/or the level control on the oscillator until the meter indicates a normal reference channel level. Set the "FREQUENCY" and "FREQ. RANGE" controls to a frequency of 1 KC. Set the second oscillator to a frequency of 1 KC and connect it to the "SIGNAL INPUT" terminals. Switch the "METER/MONITOR" switch to the "OUT X1" position and adjust the frequency of the second oscillator so that a slow beat is observed on the meter. Adjust the "FREQ. TRIM" control so that this beat has maximum amplitude. Now tune the oscillator connected to the "REFERENCE IN/OUT" terminals to about 500 cps. Set the "METER/MONITOR" switch on the "OUT X10" position and tune this oscillator slowly around 500 cps. until a slow beat is observed on the meter. In general this beat will be of very small amplitude. Adjust the "SYMMETRY" control until the amplitude of the beat so observed is a minimum. This leads to a proper adjustment of the "SYMMETRY" control.

AC BALANCE CONTROLS:
To set these controls, set the "REFERENCE MODE" switch in the "INT." position, the "FREQUENCY" and

"FREQ. RANGE" controls to a frequency of approximately 400 cps, the "SIGNAL LEVEL" control to "OFF" and the "METER/MONITOR" switch to the "OFF" position. Connect a scope between either of the red "MONITOR" terminals and ground. If a balanced scope is available, its use is to be preferred and it should be connected between the two red "MONITOR" terminals.

COARSE AC BALANCE ADJUST (R_{409}):

Remove the SIGNAL CHANNEL TUNED AMPLIFIER board from the unit (this is the first board on the right as viewed from the back of the instrument) in order to eliminate a noise source to the mixer circuit. Short the bases of Q_{403} and Q_{406} together* and adjust R_{409} until the square wave seen on the scope is a minimum. Since this adjustment is slightly temperature dependent, the unit should be allowed to reach the surrounding ambient temperature before making the above adjustment. Also, upon completing this adjustment, the wire-wound potentiometer, R_{409}, should be tapped lightly to ascertain that pot wiper is not on the edge of a wire. Observe output on scope for approximately one minute to determine that output level is not changing. Upon satisfactory completion of this test, this adjustment is concluded. Remove the short from transistors Q_{403} and Q_{406} and reinsert board directly into its connector (applicable only when extender board used).

FINE AC BALANCE ADJUST (R_{408}):

Upon completion of the "COARSE AC BALANCE" adjustment the "FINE AC BALANCE" adjust is used to further reduce the square wave output. This adjustment is made by varying potentiometer R_{408} until the square wave output as observed on the scope at the "MONITOR" terminals is a minimum. A slight adjustment of R_{408} should be made and then time allowed for all circuit elements to reach their steady state conditions before further adjusting R_{408}. This procedure should be patiently continued until the output is minimized. It is conceivable that under certain conditions this adjustment may require as much as five minutes. Upon satisfactory completion of this adjustment, reinsert the SIGNAL CHANNEL TUNED AMPLIFIER removed earlier.

NOTE: Neither of the "AC BALANCE CONTROLS" should be adjusted indiscriminately in attempting to minimize the square wave output. When it is desired to make this adjustment, the entire procedure given above should be followed.

POWER SUPPLY:

This board is located on the extreme left as viewed from the back of the instrument. It has only one adjustment which is used to set the voltage on the —24 volt line at −24 volts (R_{511} on the schematic diagram). In making this adjustment, it is necessary to remove the bottom panel from the instrument in order to gain access to the connector into which the power supply board is plugged. Connect an accurate DC voltmeter between pin 15 on this connector and the chassis. Pin 15 is the terminal on the connector closest to the bottom of the instrument. The meter should read 24 volts. If it does not, adjust R_{511} until the meter reads exactly 24 volts. Under these circumstances the voltage on pin 1 of the same connector should read —20 ±2 volts. If the voltage read on pin 1 is outside of these limits, it indicates trouble in the 20 volt regulator which should be checked.

INTERNAL OSCILLATOR ADJUSTMENT:

It is necessary to remove the top cover from the instrument in order to make this adjustment. The trimpot involved is mounted on the top edge of the printed circuit board which is mounted between the front panel and the panel carrying the connectors for the plug-in printed circuit boards. Before making this adjustment, the Q of the reference amplifier should be set to 25. If this has not been done, this adjustment should be checked. See the section on the "REFERENCE CHANNEL TUNED AMPLIFIER" adjustment for instructions on doing this. The internal oscillator adjustment is made as follows: set the "REFERENCE MODE" switch on "INT.", the "REFERENCE LEVEL" control on "1" and the "FREQUENCY" and "FREQ. RANGE" dials to a frequency of 400 cps. Connect an oscilloscope across the "REFERENCE IN/OUT" terminals. A sine wave should appear on the scope. Adjust the "OSCILLATOR LEVEL" control until the amplitude of this sine wave is 5 volts peak-to-peak, as indicated by the scope. The "OSCILLATOR LEVEL" control is now properly set.

* PAR-0409-D-MD Extender Board available which enables actual circuit board being tested to protrude beyond instrument and make all circuit points accessible.

MAINTENANCE

The most probable malfunctions and corrective procedures for them are outlined below.

	SYMPTOM	CAUSE	CURE
1	Large reading on panel meter with "METER/MONITOR" in "SIG"; "SIGNAL LEVEL" "OFF," and no signal input. Sinusoidal voltage at "MONITOR" terminals, frequency determined by "FREQUENCY" and "FREQUENCY RANGE" controls.	Signal tuned amplifier Q increased to point of oscillation.	Re-adjust "Q" and "LOW FREQUENCY BALANCE" of signal tuned amplifier as described in Section V.
2	Large reading on panel meter with "METER/MONITOR" in "REF," "REFERENCE MODE" in "SEL EXT.", "REFERENCE LEVEL" "OFF" and no reference input. Sinusoidal voltage on upper red "MONITOR" terminal, frequency determined by "FREQUENCY" and "FREQUENCY RANGE" controls.	Reference tuned amplifier Q increased to point of oscillation.	Re-adjust "Q" and "LOW FREQUENCY BALANCE" of reference tuned amplifier as described in Section V.
3	No panel meter reading with "METER/MONITOR" in "SIG" or "REF" position. Waveform at "MONITOR" terminals normal in both cases. Meter readings normal in "OUT X1" and "OUT X10"	Meter rectifier inoperative.	Check Q_{312} and associated components on board PS0112A.
4	No panel meter reading with "METER/MONITOR" in "SIG" position. Waveform at "MONITOR" terminals normal and meter readings in "REF," "OUT X1" and "OUT X10" positions also normal.	Voltmeter amplifier inoperative.	Check Q_{308}, Q_{309}, Q_{310}, Q_{311} and associated components on board PS0112A.
5	No panel meter reading with "METER/MONITOR" in "REF" position. No waveform at upper red "MONITOR" terminal. Above hold for any of the three modes of reference operation. Panel meter readings and waveforms normal in "SIG." position.	Phase shifter inoperative.	Check Q_{301} thru Q_{307} and associated components on board PS0112A. Check external phase shifter components, capacitors on "FREQ RANGE" switch, "PHASE" pot and interconnecting wiring.
6	No panel meter reading with "METER/MONITOR" in "REF" position, no waveform at upper red "MONITOR" terminal in "SEL EXT" and "INT" modes, "EXT" mode operation normal.	Reference tuned amplifier inoperative.	Check transistors and components on board TA0209B. Check external components, capacitors on "FREQ. RANGE" switch, "FREQ" control pot and interconnecting wiring.
7	No panel meter reading with "METER/MONITOR" in "SIG" position, no waveform at "MONITOR" terminals. Meter readings and waveforms normal in other "METER/MONITOR" positions.	Signal tuned amplifier inoperative.	Check transistors and components on board TA0209A. Check external components, capacitors on "FREQ. RANGE" switch, "FREQ" control pot and interconnecting wiring.
8	Panel meter does not operate in any position of "METER/MONITOR." "MONITOR" terminal waveforms normal.	Meter, and/or protective circuit faulty.	Check meter, check D_4, D_5, for short, R_{45} for open, all these on board OE0311.
9	Panel meter reads off-scale when "METER/MONITOR" in "OUT X1" or "OUT X10" positions. "ZERO" pot ineffective. Independent of "FILTER" switch position. Meter readings normal in other "METER/MONITOR" positions.	DC amplifier failure.	Check Q_{408} thru Q_{413} on board M0797. On "FILTER" switch, check R_{48}, R_{49} for open.

	SYMPTOM	CAUSE	CURE
10	Panel meter reads off-scale when "METER/MONITOR" switch in "OUT X1" or "OUT X10" positions "ZERO" pot ineffective. Condition occurs in only one "FILTER" switch position, operation in other "FILTER" switch positions normal.	Shorted capacitor in output filter circuit.	Check capacitors active in troublesome "FILTER" switch position (3 of C_{39} thru C_{46}, C_{48} thru C_{58}, C_{39} thru C_{46} on board OE0311, C_{48} thru C_{58} on "FILTER" switch).
11	Panel meter does not operate with "METER/MONITOR" in "OUT X1" position, behaves normally in all other positions.	Open multiplier resistor.	Replace R_{56} (mounted on "METER/MONITOR" switch.)
12	Panel meter does not operate with "METER/MONITOR" switch in "OUT X10" position, behaves normally in all other positions.	Open multiplier resistor.	Replace R_{57} (mounted on "METER/MONITOR" switch).
13	Recorder does not operate with "RECORDER DRIVE" switch in either position, panel meter readings with "METER/MONITOR" in "OUT X1" position normal.	Open multiplier resistor.	Check R_{46} and R_{47} on board OE0311 for open, check R_{55} ("RECORDER ADJUST") for open.
14	Recorder operates with "RECORDER DRIVE" switch in "1ma" position but not in "½ ma" position.	R_{46} open.	Replace R_{46} (board OE0311).
15	Unit inoperative, pilot lights lit.	Blown DC fuse (F501).	Connect 0-1A meter across blown F501 on board P0114. If meter reading<250 ma, replace F501. (Probable cause of failure aging of F501). If meter reading >300 ma, some portion of circuitry is taking excessive power supply current. Remove plug-in boards one at a time observing the change in load current. Normal supply currents are: TA0209A 40 ma TA0209B 40 ma PS0112A 40 ma MO797 40 ma no plug-in boards 30 ma If the change in current upon removing a particular board is larger than the value given here to account for the excessive total current reading, the trouble will lie on that board. If the current reading with all plug-in boards removed is excessive, this indicates trouble in the chassis wiring. Prime suspects in this case are: C_{59} and C_{61} which are located near the power board receptacle.

NOTE The power supply used in this instrument is current limited and will deliver less than 500 ma into a dead short. Before carrying out the checks described above measure the voltage on the −20V and −24V output lines (pins 1 & 15 respectively on S01). If either one reads 0, or close to it, the trouble is due to a short which should be tracked down by continuity checking with the power off. Continuous operation (more than 1 or 2 minutes) at high current (300 ma or more) and low output voltage (−24V line <-20V, −20V line <-15V) will cause overheating and damage to Q_{501} and/or Q_{508} (board P0114). As long as the voltages and current are within the limits specified above the unit may be operated continuously without damage for trouble-shooting purposes.

If a total current reading in excess of 500 ma is obtained the current limiting circuit is inoperative. This is almost certainly due to D_{508} (board P0114) failing to conduct when forward biased. (Replace D_{508}). Failure of the current limiting circuit could account for blowing of F501 due to capacitor-charging surge currents.

	SYMPTOM	CAUSE	CURE
16	Instrument inoperative, pilot lights out.	Blown line fuse (F1).	If F1 is blown and F501 is not, the trouble must be one of the following, (1) Short in AC wiring between line-cord F1, "POWER" switch and T1 primary. (2) Primary or secondary short in T1. (3) Any one of, or any combination of D_{501} thru D_{506} (board P0114) shorted. (4) C_{501}, C_{502} or both shorted (board P0114). (5) C_{60} shorted. (C_{60} is large 1500 mfd, 50 V can mounted on plate carrying line-cord, fuse holder and T1.) (6) Short between one of the lugs on the pilot light sockets (B1, B2, clipped to panel meter mounting brackets) and chassis.

NOTE: SLO-BLO fuses, used in these instruments, have a tendency to age, and after long use may open up even though the current through them is below their maximum. For this reason, if F1 should open up, try replacing it and operating the unit; if the replacement fuse holds it is likely that nothing is wrong with the instrument. If both F1 and F501 (board P0114) are blown it is likely that the blowing of F1 was incidental to the blowing of F501. See preceding section on blown F501.

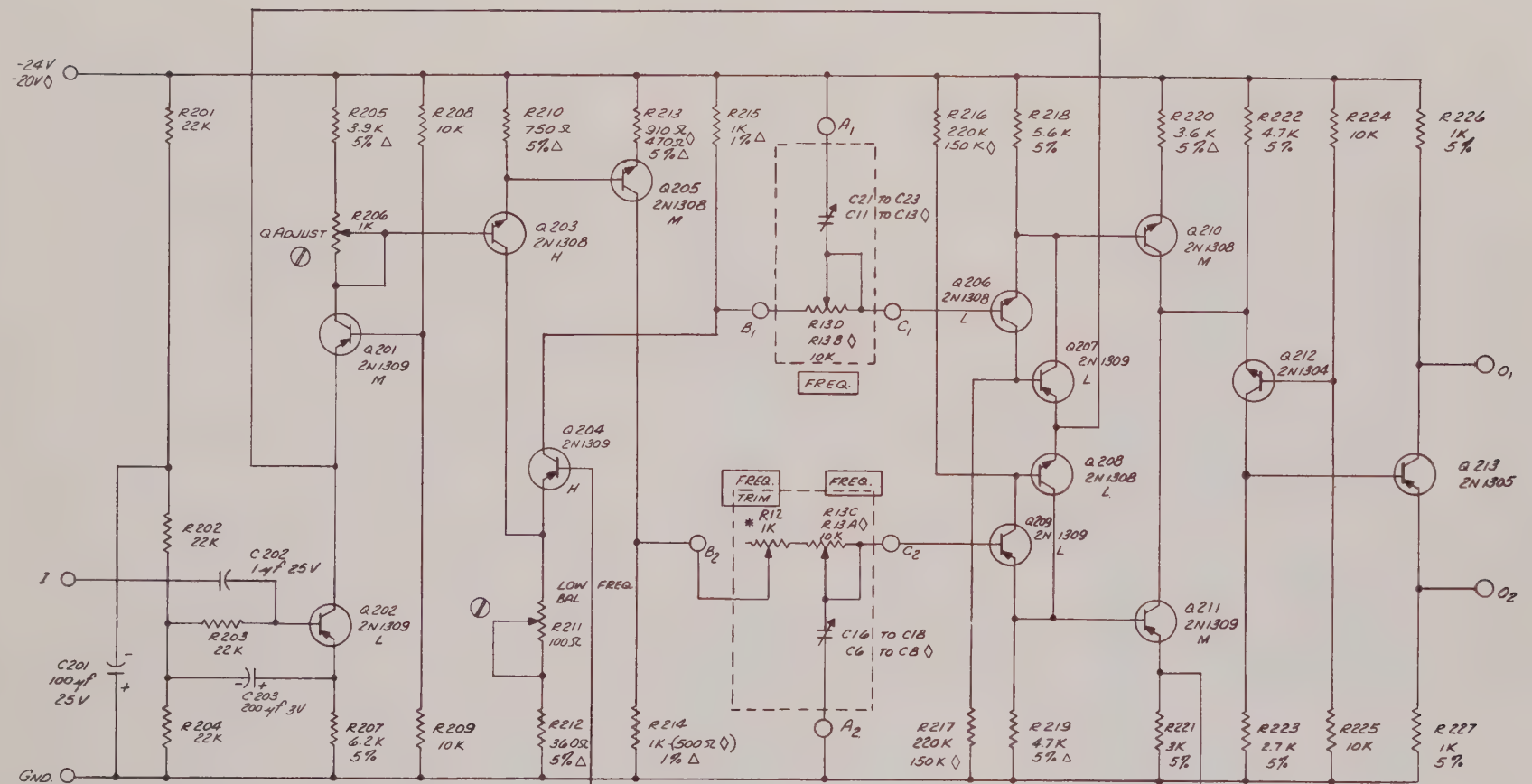
WARRANTY

Princeton Applied Research Corporation warrants each instrument of its own manufacture to be free from defects in material and workmanship. Obligations under this Warranty are limited to replacing, repairing or giving credit for the purchase price, at our option, of any instrument returned prepaid to our factory for that purpose within ONE YEAR of delivery to the original purchaser. Instruments returned to the factory are accepted only when prior authorization has been given by an authorized representative of Princeton Applied Research Corporation.

This Warranty shall not apply to any instrument, which our inspection shall disclose to our satisfaction, to have become defective or unworkable due to abuse, mishandling, misuse, accident, alteration, negligence, improper installation, or other causes beyond our control.

Princeton Applied Research Corporation reserves the right to make changes in design at any time without incurring any obligation to install same on units previously purchased.

This Warranty is in lieu of, and excludes all other warranties or representations, expressed, implied or statutory, and all other obligations or liabilities of Princeton Applied Research Corporation including special or consequential damages, and no other source is authorized to assume for Princeton Applied Research Corporation any other liability.



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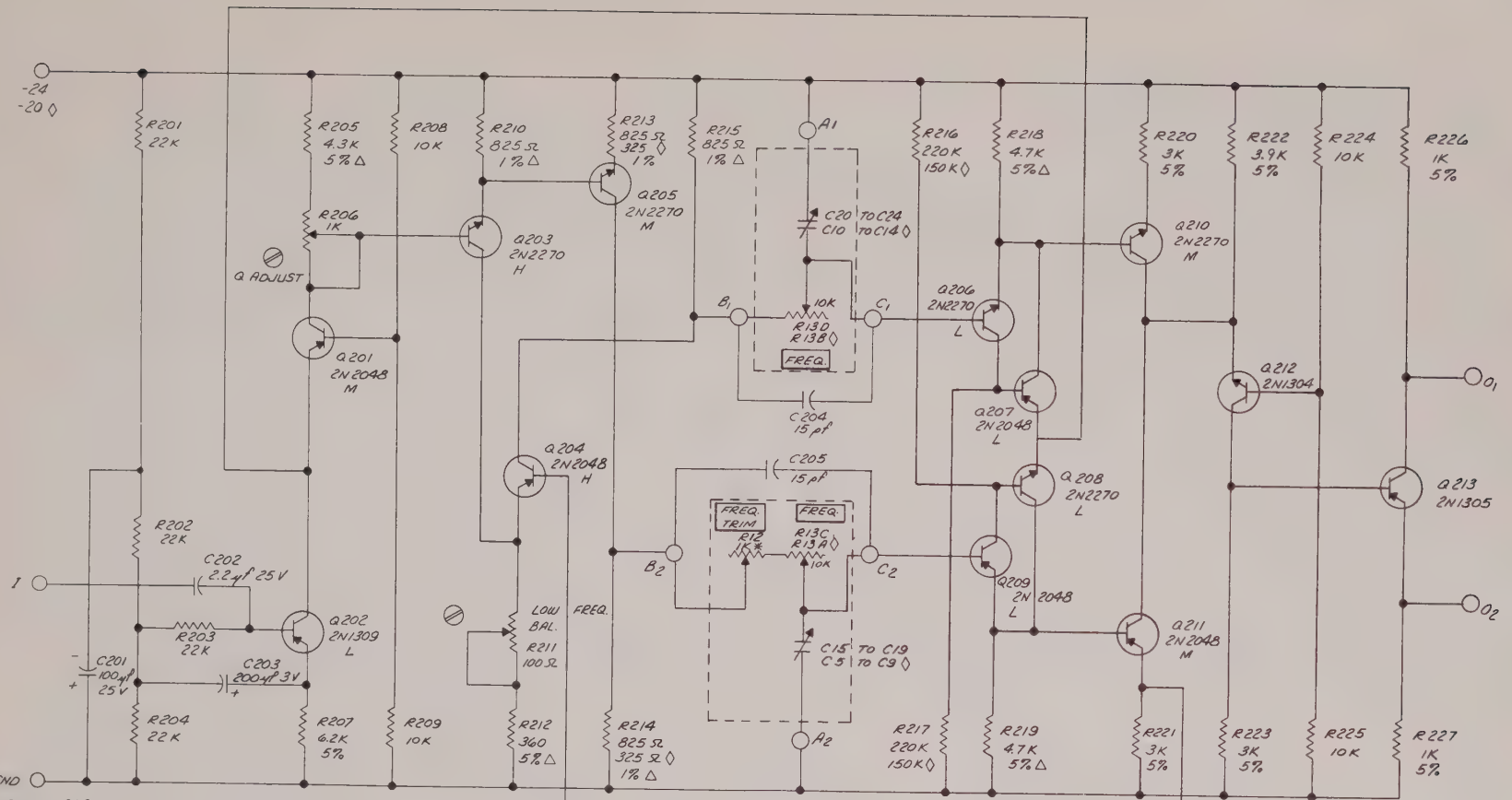
1 -24	2 O_1	3 O_2	4 N.C.	5 C_2	6 A_2	7 B_2	8 GND	9 C_1	10 B_1	11 A_1	12 N.C.	13 N.C.	14 N.C.	15 I

-20◊

CONNECTOR SO4 (REF) OR SO5 (SIGNAL)
PIN CONNECTIONS

NOTES
1. * NOT USED IN REFERENCE CHANNEL
2. △ HIGH STABILITY TYPE
3. ◊ VALUES USED IN SIGNAL CHANNEL ONLY
4. (H) SELECTED FOR $\beta \geq 200$ AT 5 MA
5. (M) SELECTED FOR $\beta \geq 150$ AT 5 MA
6. (L) SELECTED FOR $\beta \geq 100$ AT 5 MA

MODEL JB 4 REFERENCE AND SIGNAL CHANNEL TUNED AMPLIFIER CIRCUIT BOARDS NO. TA0209A AND TA0209B



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1 / 24	2 / O_1	3 / O_2	4 / NC	5 / C_2	6 / A_2	7 / B_2	8 / GND	9 / C_1	10 / B_1	11 / A_1	12 / N.C.	13 / N.C.	14 / N.C.	15 / I

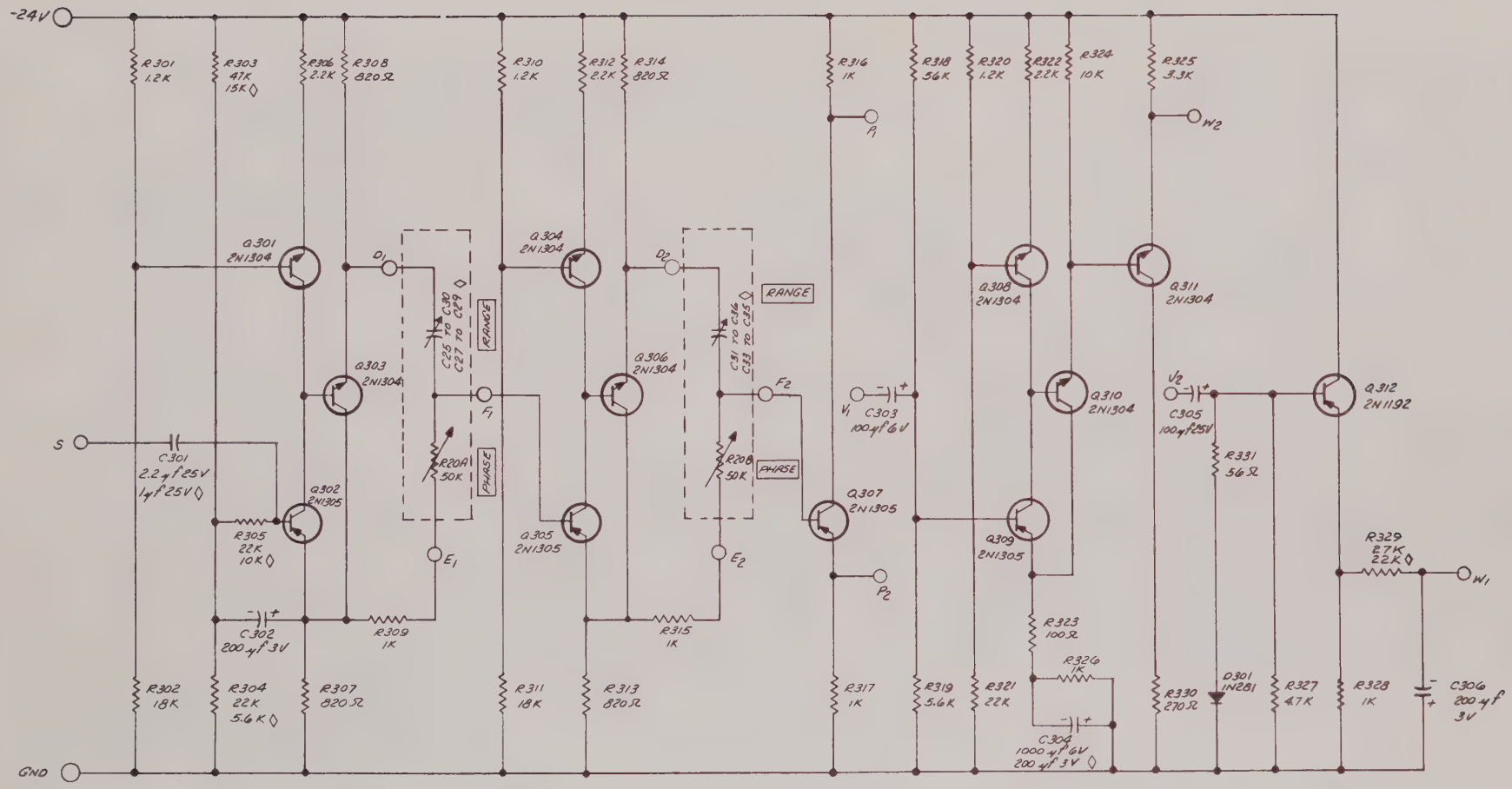
-20 ◊

CONNECTOR S04 (REF) OR S05 (SIGNAL)
PIN CONNECTIONS

NOTES

1. * NOT USED IN REFERENCE CHANNEL
2. △ HIGH STABILITY TYPE
3. ◊ VALUES USED IN SIGNAL CHANNEL
4. (H) SELECTED FOR $B \geq 200$ AT 5 MA
5. (M) SELECTED FOR $B \geq 150$ AT 5 MA
6. (L) SELECTED FOR $B \geq 100$ AT 5 MA

MODEL JB5 REFERENCE AND SIGNAL CHANNEL TUNED AMPLIFIER CIRCUIT BOARDS NO. TA0209A AND TA0209B



1 -24	2 V1	3 W2	4 V2	5 W1	6 P1	7 F2	8 P2	9 GND	10 D2	11 E2	12 F1	13 D1	14 E1	15 S

CONNECTOR S03
PIN CONNECTIONS

NOTE
◊ VALUES USED IN JB4 ONLY

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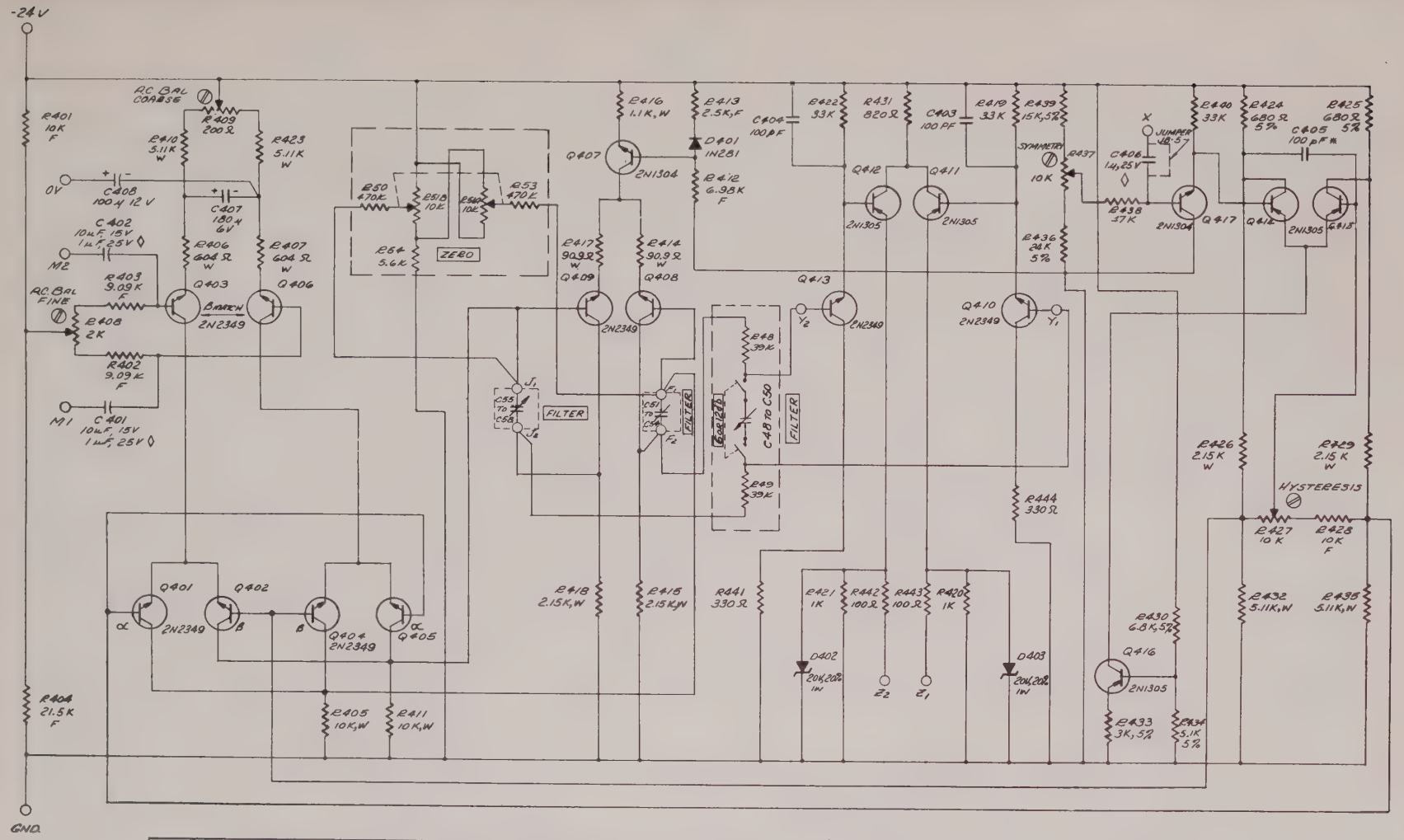
MODELS JB4 AND JB5

PHASE SHIFTER AND VOLTMETER SCHEMATIC

CIRCUIT BOARD NO. PS0112A



1 -24	2 X	3 NC	4 Y2	5 Z2	6 Z1	7 Y1	8 GND	9 0V	10 J2	11 F2	12 F1	13 J1	14 M2	15 M1

CONNECTOR S02
PIN CONNECTIONS

NOTES
1. ◊ VALUES USED ON JB-4 ONLY
2. * NOT USED ON JB 4
3. F 1%, ½ W, METAL FILM
4. W 1%, 3 W, WIRE WOUND
5. ALL OTHER RESISTORS, ½ W, 10% COMPOSITION, EXCEPT 5% AS NOTED

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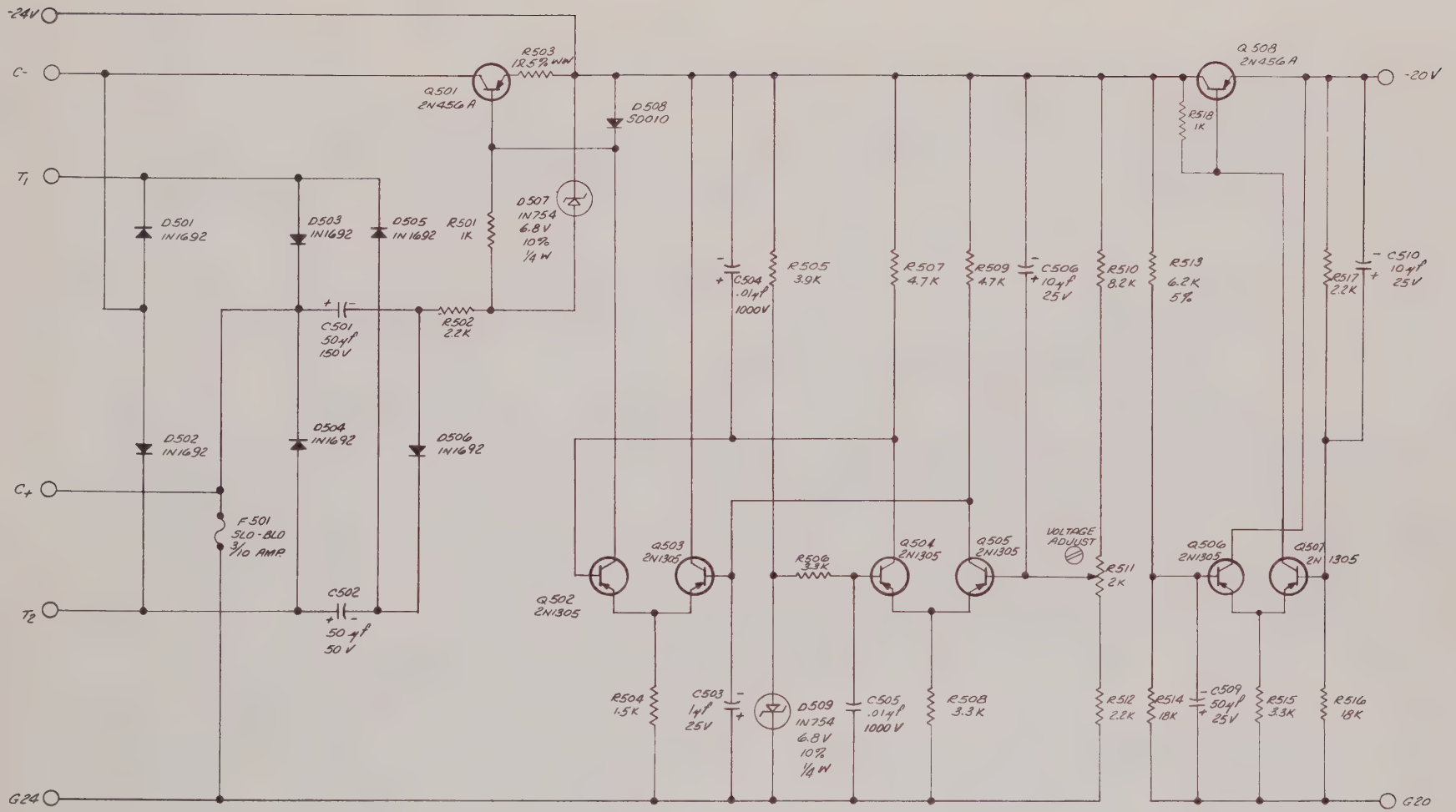
MODELS JB-4 AND JB-5 MIXER - DC AMPLIFIER SCHEMATIC
CIRCUIT BOARD NO. MO 797



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
-20	G20	N.C.	C+	N.C.	C-	N.C.	N.C.	N.C.	T2	T1	G24	N.C.	N.C.	-24

CONNECTOR 501
PIN CONNECTIONS

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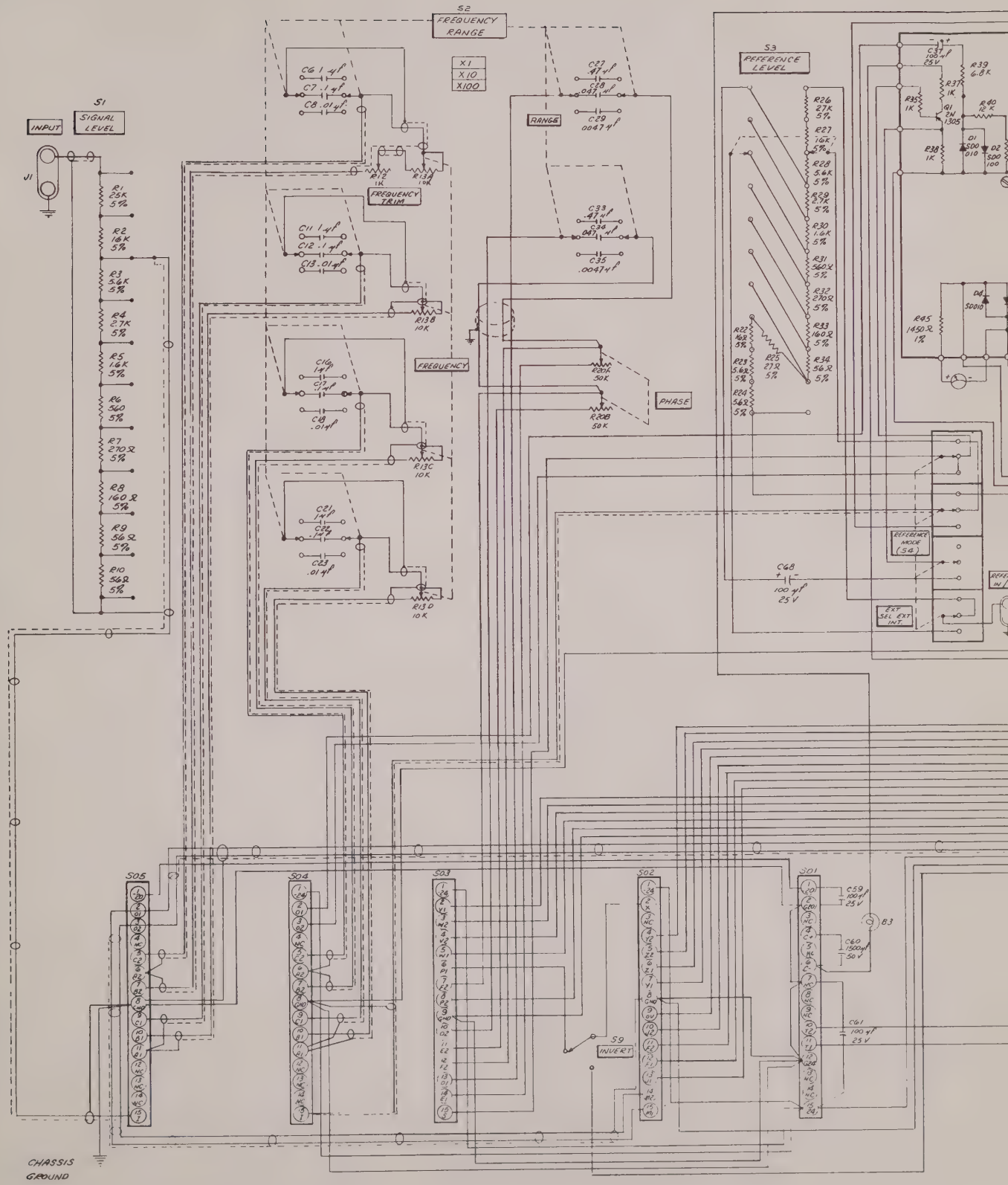
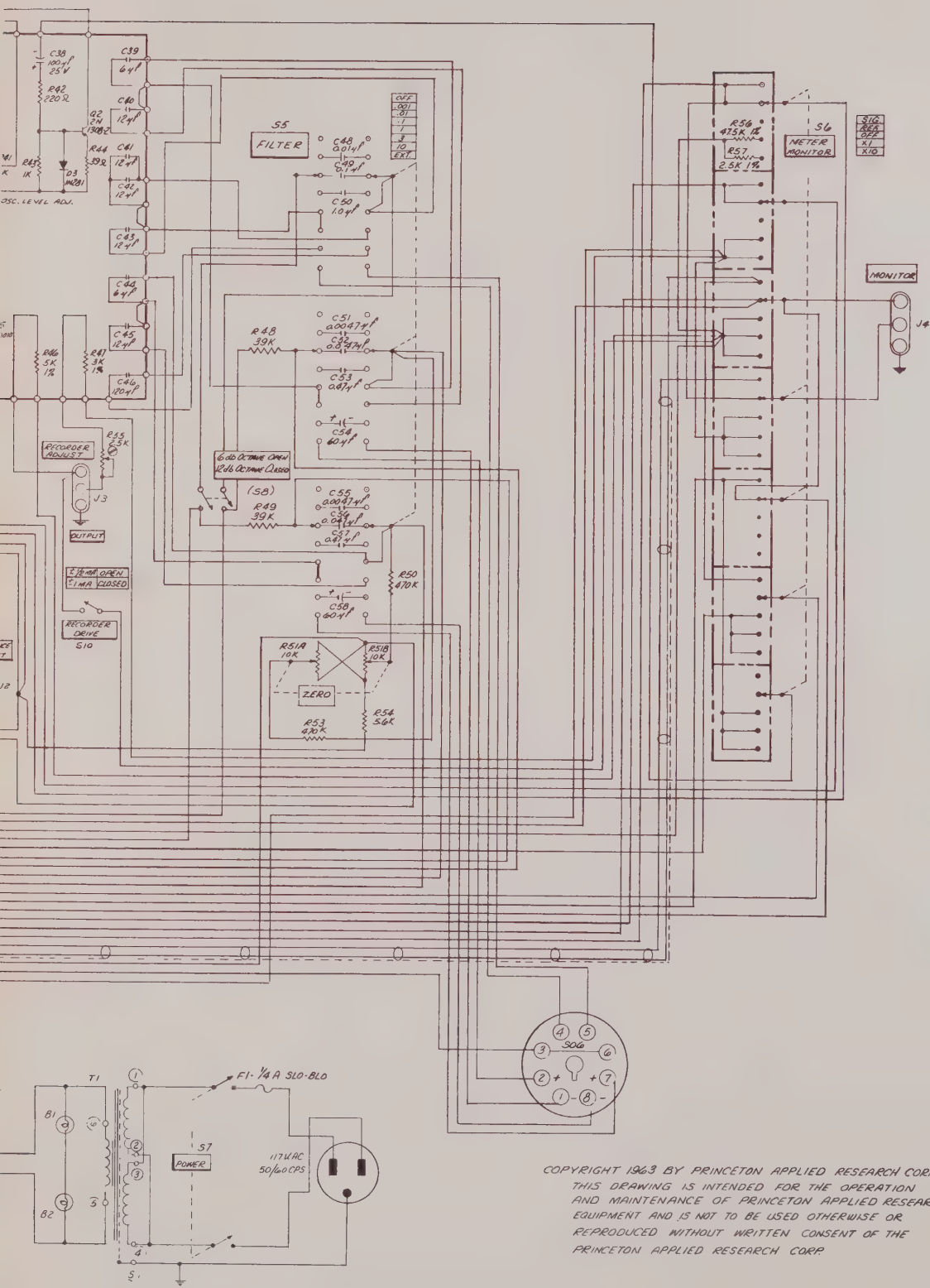
MODELS JB4 AND JB5 POWER SUPPLY CIRCUIT BOARD P0114


S2
FREQUENCY RANGE
X1
X10
X100
RANGE
S1
INPUT
SIGNAL LEVEL
J1
R1 25K 5%
R2 16K 5%
R3 5.6K 5%
R4 2.7K 5%
R5 1.6K 5%
R6 560 5%
R7 270Ω 5%
R8 160Ω 5%
R9 56Ω 5%
R10 56Ω 5%
C6 1 µf
C7 .1 µf
C8 .01 µf
C11 1 µf
C12 .1 µf
C13 .01 µf
C16 1 µf
C17 .1 µf
C18 .01 µf
C21 1 µf
C22 .1 µf
C23 .01 µf
C27 .47 µf
C28 .047 µf
C29 .0047 µf
C33 .47 µf
C34 .047 µf
C35 .0047 µf
R12 1K
R13A 10K
R13B 10K
R13C 10K
R13D 10K
FREQUENCY TRIM
FREQUENCY
PHASE
R20A 200K .5W
R20B 50K
S3
REFERENCE LEVEL
R26 27K 5%
R27 16K 5%
R28 5.6K 5%
R29 2.7K 5%
R30 1.6K 5%
R31 560Ω 5%
R32 270Ω 5%
R33 160Ω 5%
R34 56Ω 5%
R22 160Ω 5%
R23 56Ω 5%
R24 56Ω 5%
R25 27Ω 5%
C37 100 µf 25V
R39 6.8K
R37 1K
R35 1K
Q1 2N 1305
R40 2K
R38 1K
D1 SD010
D2 SD0100
D4 SD010
R45 1450Ω 1%
REFERENCE MODE (S4)
EXT SEL EXT INT.
C68 100 µf 25V
S5
S4
S3
S2
S1
C7
S9
INVERT
C59 100 µf 25V
C60 1500 µf 50V
C61 100 µf 25V
B3
CHASSIS GROUND



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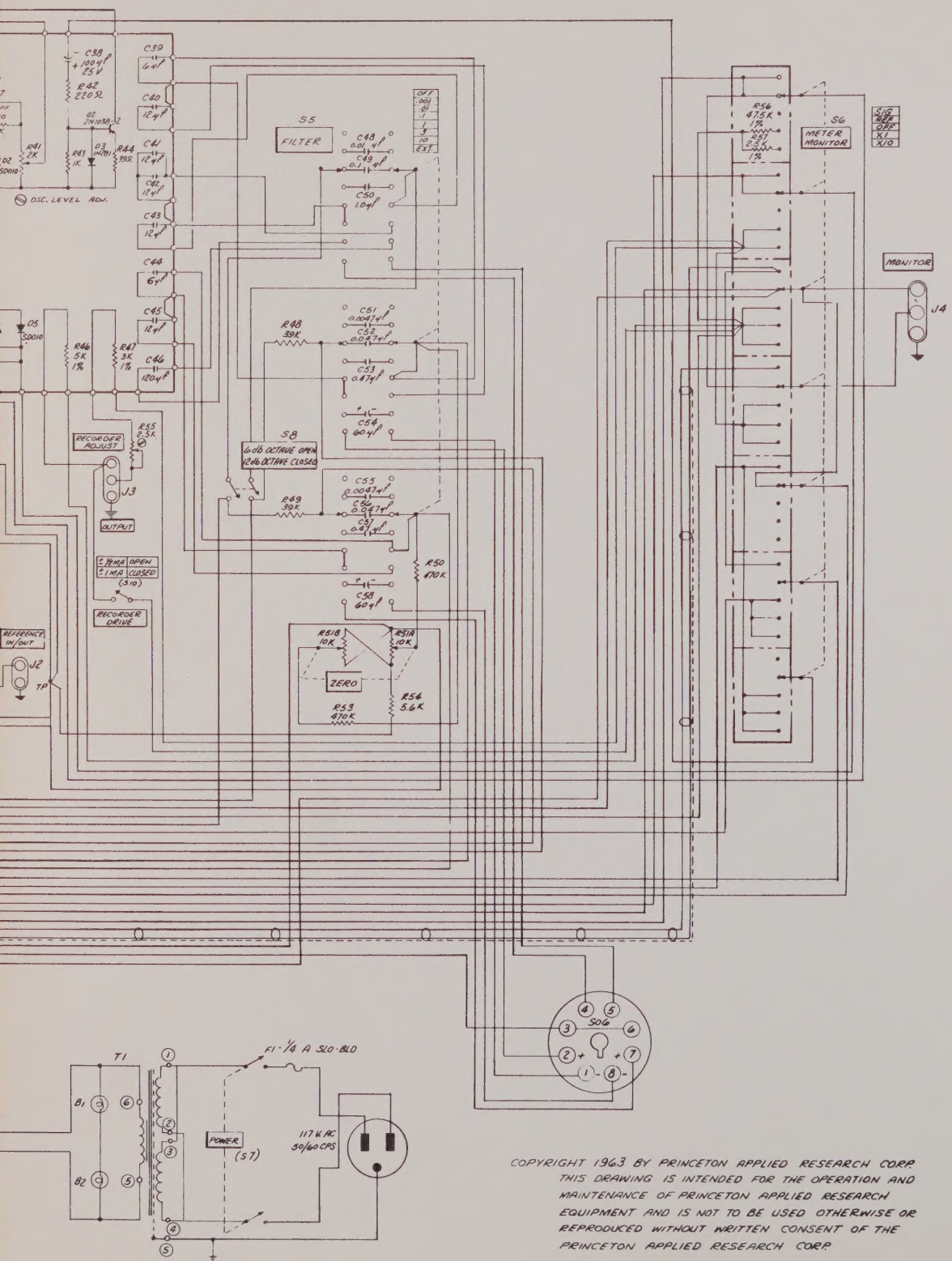
MODEL JB 4
CHASSIS WIRING SCHEMATIC

INPUT
J1
S1
SIGNAL LEVEL
FREQUENCY RANGE
(S2)
X1
X10
X100
X1K
X10K
FREQUENCY TRIM
FREQUENCY
RANGE
PHASE
S3
REFERENCE LEVEL
REFERENCE MODE (S4)
EXT. SEL. EXT. INIT.
S01
S02
S03
S04
S05
INVERT
(S9)
OVER LOAD
CHASSIS GROUND



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MODEL JB5
CHASSIS WIRING SCHEMATIC

MP MASTER
MA28902